STATE OF CALIFORNIA
The Resources Agency
Department of Water Resources

in cooperation with
County of Sonoma

BULLETIN No. 118-4

EVALUATION OF GROUND WATER RESOURCES: SONOMA COUNTY

Volume I: GEOLOGIC AND HYDROLOGIC DATA

save water
DWR

DECEMBER 1975

CLAIRE T. DEDRICK
Secretary for Resources
The Resources Agency

EDMUND G. BROWN JR.
Governor
State of California

RONALD B. ROBIE
Director
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FOREWORD

Since Sonoma County was first settled, ground water has played an important role in domestic, agricultural, and urban water development. Because ground water will continue to be important to the future development of Sonoma County, a cooperative study of the ground water resources of the County was begun in 1971 to provide the County Planning Department with information needed to prepare pertinent elements of its General Plan and also to provide the State with information on the ground water resources needed for statewide planning.

This bulletin provides basic information on the geology and hydrology of the ground water systems underlying Sonoma County as well as information on rural septic tank systems. This information will be useful to those involved in all phases of planning and to those interested in the development of water wells and the placement of septic systems in rural areas.

As part of the continuing effort to integrate the use of surface water, ground water, and reclaimed waste water, the Department and the Sonoma County Water Agency will start the second phase of this study in late 1975. As part of the second phase, mathematical models will be developed for the major ground water basins underlying the Santa Rosa Plain and the Petaluma and Sonoma Valleys. The models developed will represent the ground water basin's reaction to rainfall, runoff, irrigation, and man's alteration of the earth's surface and resources. Once verified by historic events, the model is used to predict reactions to future conditions.

The second phase will evaluate the probable future water demands of Sonoma County and several alternative mixes of Russian River water, reclaimed waste water, ground water, and water conservation measures. Each of the alternatives will be tested on the ground water model to determine its effect on the ground water resource. The product of the study will be an evaluation of each of the alternative management plans and recommendations on which of the alternatives appear superior from economic, engineering, and environmental bases.

Ronald B. Robie

Ronald B. Robie, Director
Department of Water Resources
The Resources Agency
State of California

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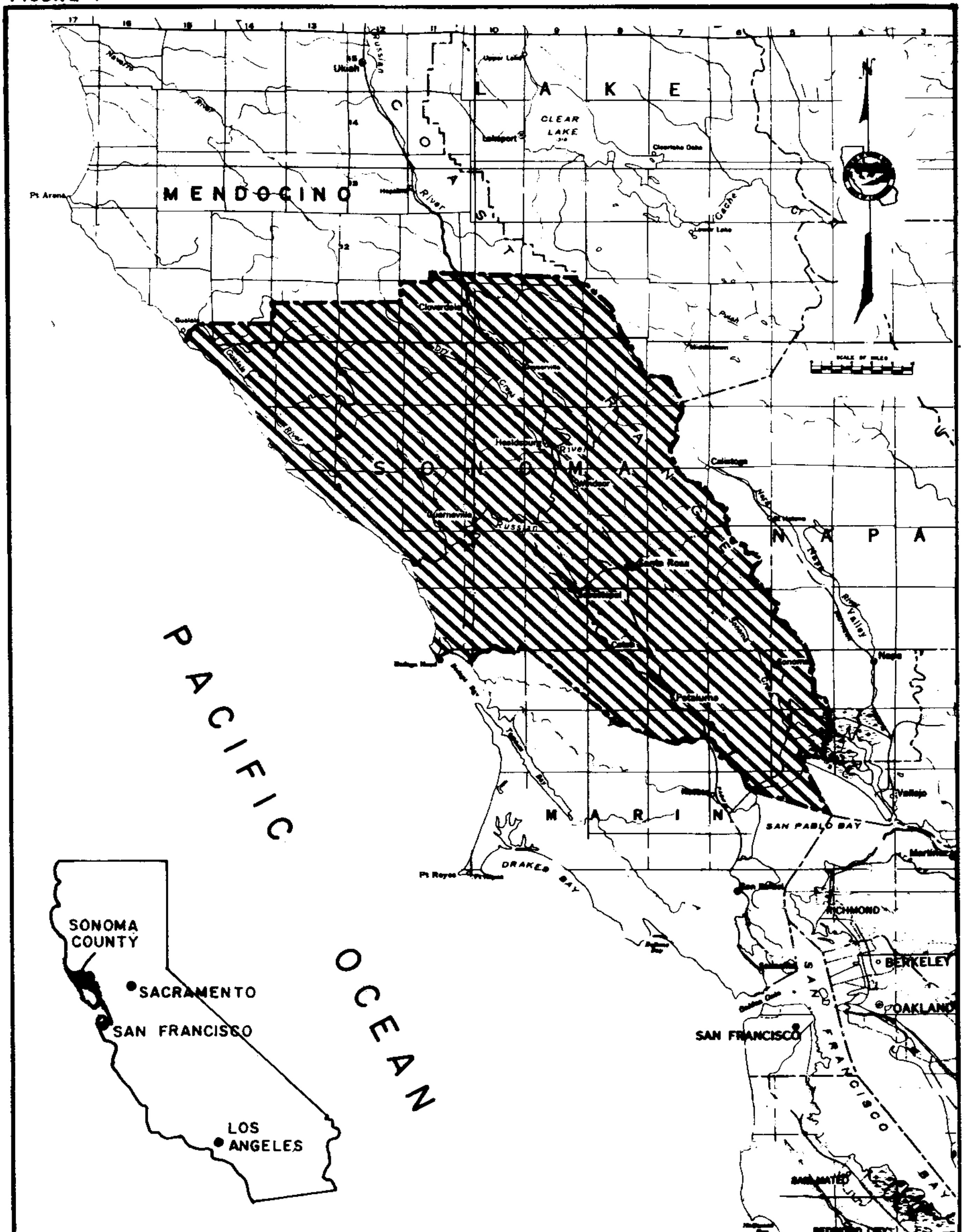
Their help is gratefully acknowledged.

FIGURE 1



AREA OF INVESTIGATION

CHAPTER I. INTRODUCTION AND SUMMARY

Use of ground water in Sonoma County has been increasing steadily for the last 25 years. Today, with more than 10,000 water wells identified in the county, ground water continues to be an important natural resource. Ground water in Sonoma County is used for domestic, municipal, industrial, and agricultural purposes. Municipal water needs of the cities of Santa Rosa, Cotati, Sonoma, and Petaluma are met primarily from surface water supplies provided by the Sonoma County Water Agency. The cities of Cloverdale, Healdsburg, Sebastopol, and Rohnert Park rely principally on ground water.

The continuing population growth in Sonoma County has been accompanied by an increasing stress on the ground water resource. In order to obtain better information on which to base decisions, the Sonoma County Planning Department requested the Department of Water Resources to undertake a cooperative investigation of the ground water resource of the county, including the effect on this resource caused by urbanization in rural areas served by individual domestic well and septic tank systems. Information requested by the county included (1) the identification of all water purveyors; (2) the identification of all sanitary sewer systems; (3) the geologic parameters involved in the recharge, transmission, and withdrawal of ground water; (4) the chemical and bacteriological quality problems in the county; and (5) the identification and evaluation of the various ground water basins in the county.

The study was conducted on a cooperative basis and accomplished two goals. First, the study developed ground water data that the county will need in order to implement water development guidelines and the Department will need to evaluate the extent of the ground water resource for use in statewide planning. Second, the fact that the study was undertaken cooperatively ensured that planning would be based on local conditions and that local agencies would be involved in the effort and acquainted with the results and the bases upon which they were reached.

Description of the Area

Sonoma County is situated north of San Francisco Bay, as shown on Figure 1. Santa Rosa, the county seat, had a 1970 population of 50,006. The city is the center of commerce of the North Bay area, and is served by U. S. Highway 101, two railroads, and two scheduled airlines. Other population centers include Petaluma (population 24,870) in the southern part of the county, Sonoma (population 4,112) in Sonoma Valley, Sebastopol (population 3,993), Healdsburg (population 5,438), and Cloverdale (population 3,251).

An additional 6.64 percent of the county has soil conditions which may be acceptable for septic tanks, but on-site tests should be required to determine if this is the case. The remaining 92.75 percent of the county is underlain by soils that are totally unacceptable for the satisfactory placement of septic tanks and leach lines due to inadequate percolation rates, steepness of slope, depth to rock, or depth to water. Recommended acceptable areas for septic tank siting are presented on Plate 2.

4. <u>Ground Water Resources</u>. Seven ground water basins in the county have been identified; these comprise 16 percent of the total area of the county. Adjacent upland ground water areas, underlying an additional 26 percent of the county, also have been identified. Most of the 10,199 identified water wells are located in these seven ground water basins and in the upland areas. The average depth to water was tabulated for each section for which water level data were available. In many cases, adjacent wells of differing depths had markedly different water levels.

Well records dating back to 1949 show that there have been few significant changes in water levels over the years. Natural recharge areas were identified in the valley areas of the Russian River and Dry Creek as well as the hill area southwest of Sebastopol. Previous studies of this latter area indicate that its recharge capability is about 21,000 acre-feet per day (26 cubic hectometers per day).

The density of water wells, as well as the percentage of wells with sanitary seals, also was determined. In several mile-square sections of land, there are more than 100 water wells; one section southwest of Sebastopol contains 180 water wells. In many sections with numerous wells, less than half of them have sanitary seals.

In Sonoma County, there are at least 400 springs, many of which yield potable ground water. There are also thermal springs which yield highly mineralized, unpotable ground water.

The total amount of ground water in storage in Sonoma County was determined through the use of a computer-assisted program. The program indicated that there are about 19 million acre-feet (23,000 cubic hectometers) of ground water in storage. However, usable storage capacity could not be determined due to a lack of adequate data on recharge, transmissivity, pumpage, and safe yield.

5. <u>Water Quality Hazards</u>. Most ground water developed in Sonoma County is usable for domestic purposes. Only in a few areas are chemical constituents present which render the water unpotable. Boron is present in the water from a number of wells; this constituent, although not a hazard

to drinking water, may be injurious to toxic to a variety of plants and trees. Sodium, which also is an agricultural hazard, is present in a number of wells throughout the county. Water used for domestic purposes decreases in quality with an increase in salinity, iron and manganese, hardness, and total dissolved solids. Each of these four hazards was found in certain localities in the county.

Study Continuation

Ground water is an important resource in Sonoma County. Many rural areas are entirely dependent on ground water. The use of ground water for storage in combination with surface water supplies may provide more efficient utilization of water resources. There is a need to continue the current investigative effort to develop additional ground water data, determine the usable ground water storage capacity, ascertain the dynamic response of the various ground water basins and contiguous ground water areas, and develop water resources management plans for Sonoma County. The program should include:

1. Establishment of the following priority for the further investigation of the various ground water basins because usable ground water storage capacity could not be determined during the present study:

   Group I: Santa Rosa Valley (including Dry Creek and Rincon Valley), Petaluma Valley, Sonoma Valley, and the Kenwood Valley-Glen Ellen area.

   Group II: Alexander Valley, Knights Valley, and Lower Russian River Valley.

   Group III: Ground water areas outside of boundaries of ground water basins.

   Investigation of the Group I basins should include the study of the entire geohydrologic system and an evaluation of the capability of the aquifer system to support municipal, and other high demand, water systems. Investigation of the Groups II and III basins and areas should include an identification of the aquifer systems and an evaluation of efficient use of ground water.

2. Establishment of a network of monitoring wells of sufficient density to provide data on the identification and configuration of the potentiometric surfaces of the various aquifer systems and the determination of the direction of ground water flow in them.

3. Development of mathematical models of the Group I more intensely developed basins in order to evaluate alternatives to meet the water demands of these basins to the year 2000. Data needed for each model include land use, water use and pumpage, population projections, precipitation, aquifer characteristics, and transmissivity values.

4. Development, testing, and evaluation of conjunctive use plans for the Group I basins and recommendation of the type of ground water basin plan most appropriate for each basin.

5. Development of hydrologic data as in No. 3, above, for use in estimating usable ground water storage and safe yield in less-developed basins where the development of a ground water model is not justified at this time.

6. Identification of natural and artificial recharge sites and determination of their infiltration characteristics. Sources of water for recharge (both natural and treated) should be identified and evaluated. The effects of artificial and natural recharge of water on ground water withdrawals should be evaluated.

7. Additional study of water quality problems, such as iron and manganese, should be made to determine their cause, effect, and remedy.

CHAPTER II. GEOLOGY AND HYDROLOGY

The study of the geologic and hydrologic aspects of Sonoma County provide a rational basis for the evaluation of the various ground water parameters. Before decisions affecting the mode, occurrence, quality, or use of ground water can be made, a knowledge of these two basic sciences is necessary.

Geology: A Fundamental Part of Ground Water Studies

Ground water exists at many places beneath the surface of the earth. It is normally hidden from view but, on occasion, can be seen flowing from springs and wells or seeping into tunnels. Certain properties of the various geologic materials control the ability of ground water to enter into, move through, be stored in, or be extracted from the ground. Therefore, an understanding of geology is necessary in order to gain an understanding of ground water found within a particular area of investigation. A basic part of the study of the geology of an area includes the preparation of a map showing surficial exposures of each rock type. Interpretation of the map facilitates the study of the underground configuration, characteristics, and physical properties of these materials. This, in turn, enables the evaluation of ground water storage, movement, and yield, as well as the identification of areas of ground water quality problems, recharge, and extraction.

Geologic Formations

The fundamental unit of a geologic study is the geologic formation. A formation has been defined as any assemblage of rocks which have some character in common, whether of origin, age, or composition. In this sense, the term "rock" is defined as any naturally occurring part of the earth's crust, and includes hard, dense granite, lava ash, clay, sand, and even loose, uncohesive soil.

The rocks in Sonoma County have been divided into three major rock groups, viz. igneous, sedimentary, and metamorphic. Igneous rocks were formed from the cooling, solidification, and crystallization of molten magma or lava and are of two types, intrusive and extrusive. When formed at depths of several miles, they are spoken of as intrusive. These rocks contain mineral crystals that can be seen by the unaided eye and are characterized by the granitic rocks exposed at Bodega Head. When formed on the surface, such as a lava flow, igneous rocks are spoken of as being extrusive. Most crystals in this latter rock type are periods have been further subdivided into epochs. Present-day time is included in the Holocene Epoch, which goes back 10,500 years.

Another way of looking at geologic time since the beginning of the Paleozoic Era is to compress it into an imaginary one year of time. Were this the case, the Paleozoic Era would have lasted eight months and the Mesozoic Era another three and one-half months. The Ceozoic Era would have begun during the next-to-last week of the year. The entire history of man, stretching back over 2,000 years, would have been allowed only about 15 minutes at the close of the year.

Figure 2 presents a stylized view of geologic time showing the significant events and creatures of geologic history. Figure 3 is a geologic time scale showing the relative time position of the various geologic formations in Sonoma County.

The Relationship Between Geologic Materials and Ground Water

The geologic formations which underlie Sonoma County can be divided into two basic groups, viz. water-bearing and nonwater-bearing. A water-bearing formation is one that readily absorbs, transmits, and yields usable quantities of ground water to wells. Conversely, a nonwater-bearing formation is one that yields only limited quantities of water to wells. In some cases, nonwater-bearing formations can yield mineralized, unpotable water. With but one exception, all of the water-bearing formations of Sonoma County are of Cenezoic age. Furthermore, nonwater-bearing rocks are all "hard rocks", that is, they are consolidated and massive. Conversely, most of the water-bearing rocks include soft sandstone, clay, alluvial soils, and river gravels.

Nearly all of the materials that make up the water-bearing formations have open spaces containing ground water. The size of these openings ranges from minute pores in clays to intergranular openings in deposits of sand and gravel. The porosity, or percentage of the total volume of the openings, is not necessarily indicative of the ease with which ground water moves through the material. If the openings are very small, or if they are not connected, the material has a low permeability. Materials of low permeability, such as clay, transmit very little water. In contrast, materials of high permeability, such as river gravel, yield large amounts of ground water. A geologic bed, or stratum, which readily transmits ground water (i.e., has a high permeability) is called an aquifer. In contrast, materials which contain ground water but cannot transmit extractable quantities (i.e., have low permeabilities) are called confining beds. Certain strata can act as aquifers in one area and as confining beds in another area because of lateral changes in permeability resulting from changes in the physical characteristics of the materials.

FIGURE 2

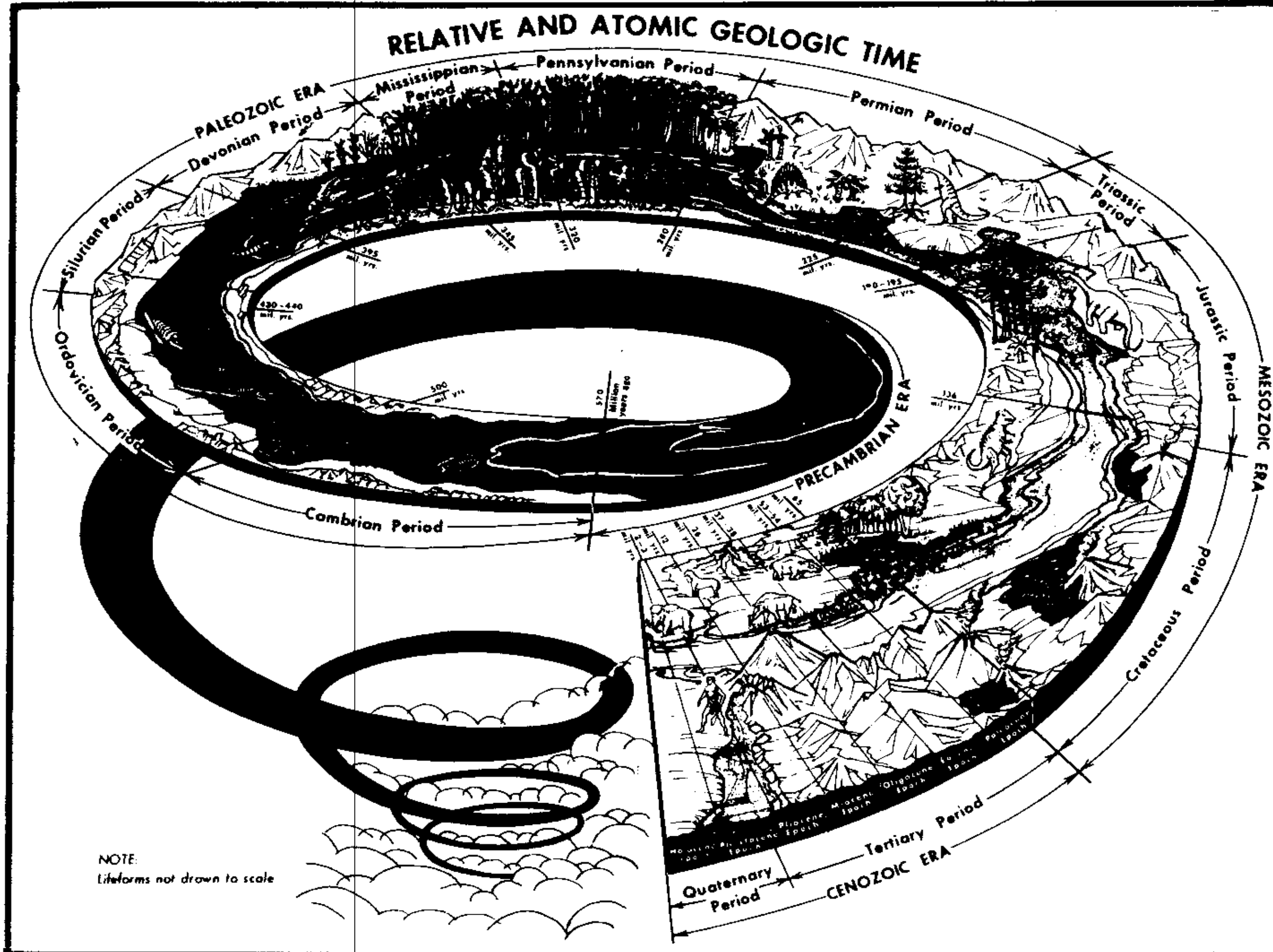
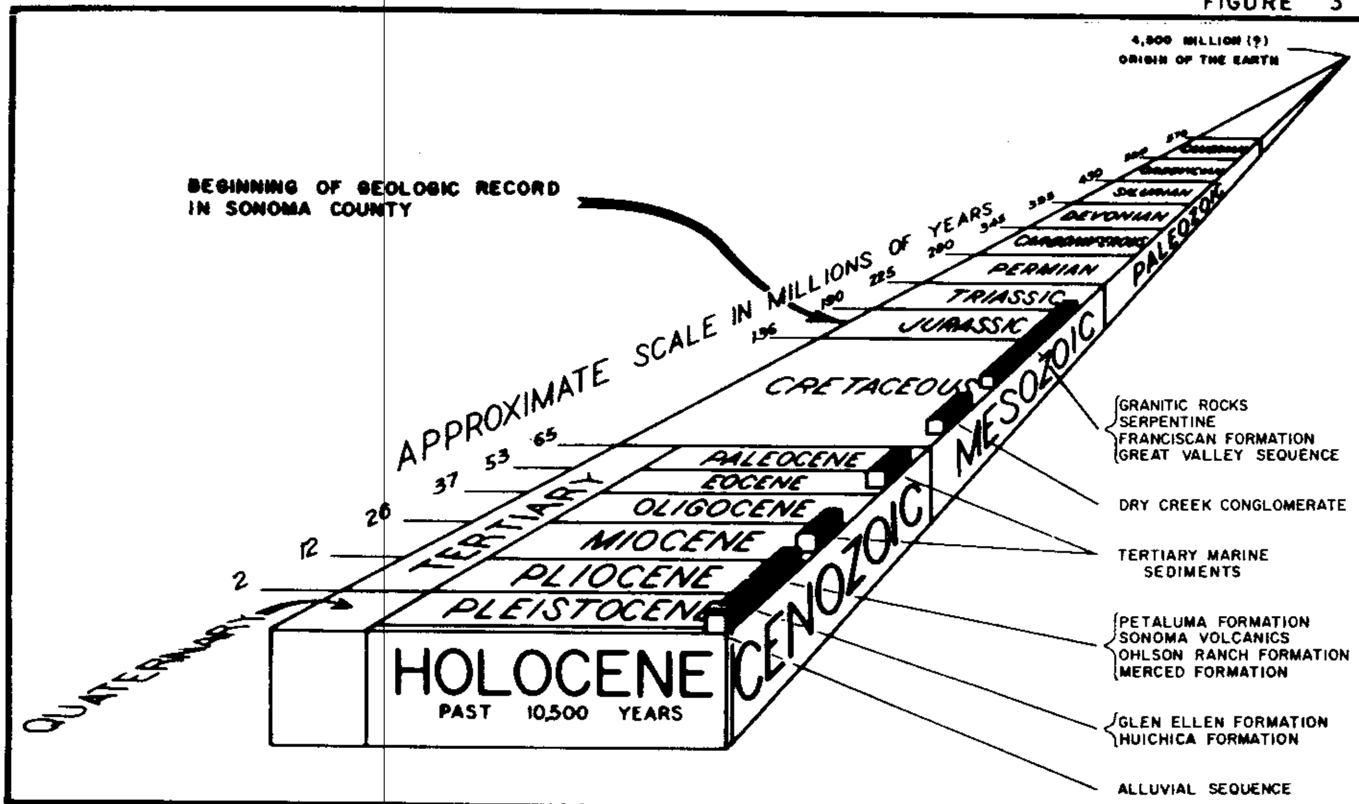


FIGURE 3



LOOKING BACK IN GEOLOGIC TIME

Ground water exists in two zones beneath the ground surface, as shown on Figures 4 and 5. The upper zone is the zone of aeration. Here, most openings in the geologic materials are partly filled with air and partly with water. Wells do not produce ground water from the zone of aeration because the molecules of water adhere tightly to the various geologic materials. If perched ground water occurs in the zone of aeration, it is contained in an isolated saturated zone which is separated from the main ground water body by an underlying impermeable stratum. Well "B" on Figure 4 represents a well producing from a perched aquifer.

In the lower zone, or zone of saturation, all of the interconnected openings in the geologic materials are filled with ground water; little or no air is present. Ground water exists in this lower zone under either unconfined or confined conditions. An aquifer containing unconfined ground water is one that is not overlain by a confining bed. The upper surface of an unconfined body of ground water is called the water table. It is represented by the level of water in a well tapping unconfined ground water. Well "D" on Figure 4 represents a well producing from an unconfined aquifer. Unconfined ground water moves very slowly in the direction of the downward slope of the water table.

A confined aquifer is one that is overlain by relatively impermeable material and is isolated from overlying aquifers except in areas of recharge. Ground water contained in confined aquifers is under pressure, and the level to which this confined ground water will rise in a nonpumping well is the potentiometric surface of the ground water. This latter is an imaginary surface that represents the upward pressure exerted by the confined ground water on the materials overlying it. Where the potentiometric surface is below ground, water will rise in the well to some point above the top of the aquifer, as represented by Well "A" on Figure 5. If the potentiometric surface is above ground, the well will flow as represented by Well "C".

The stratification of aquifers and confining beds is the result of deposition under continually changing environments. Coarse-grained deposits, sand and gravel, are laid down along stream channels. They are coarsest at the apex of alluvial fans and become finer-grained the farther removed they are from the mountains. Silts and clays are deposited by slow-moving streams, in flood areas adjacent to active channels, and in lakes, swamps, and bays.

Hydrology: From Precipitation to Well

The earth's water circulatory system is known as the hydrologic cycle. In this cycle, shown on Figure 6, water evaporates from the ocean and other bodies of water; it is also given off into the atmosphere by plants. This water collects as clouds and then returns to earth as precipitation. The precipitation either forms

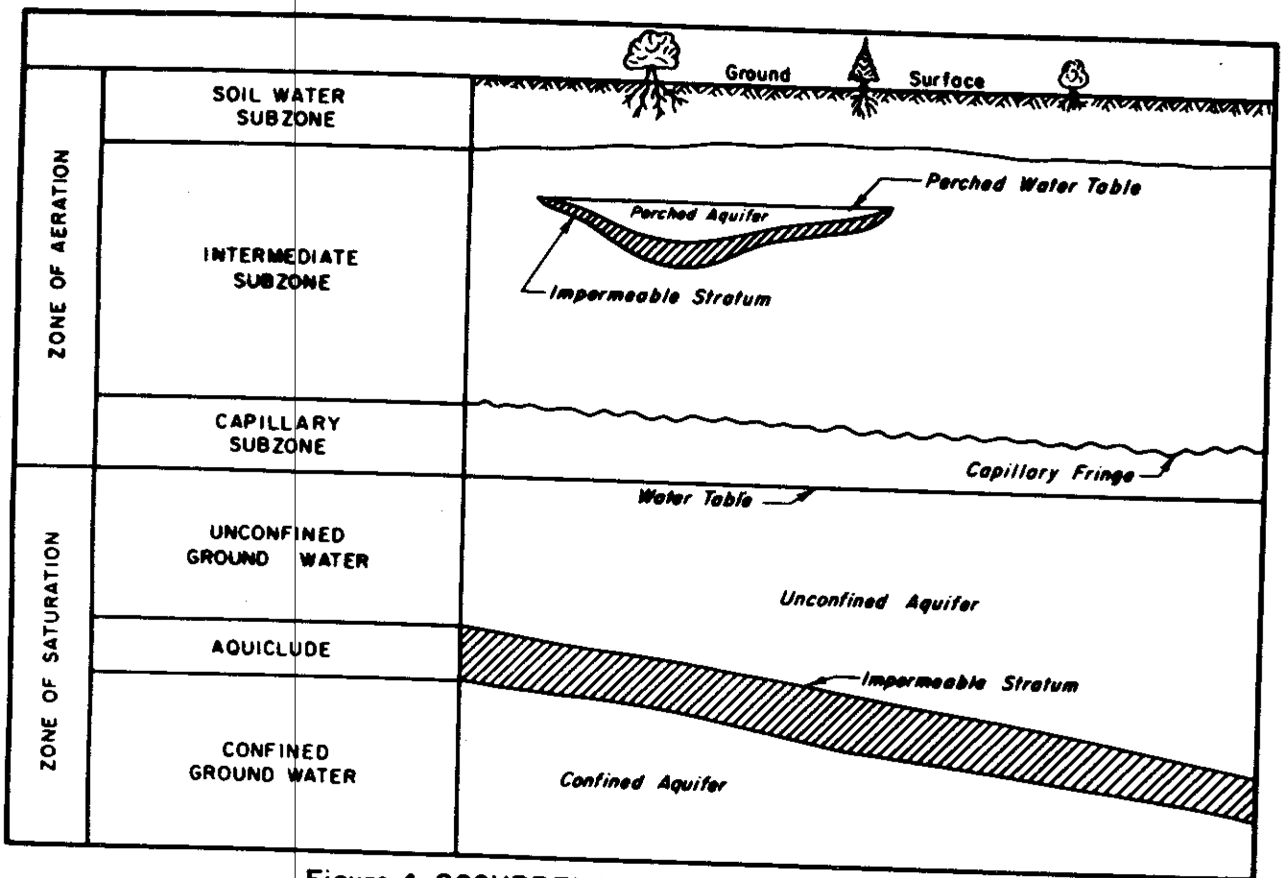


Figure 4 OCCURRENCES OF GROUND WATER

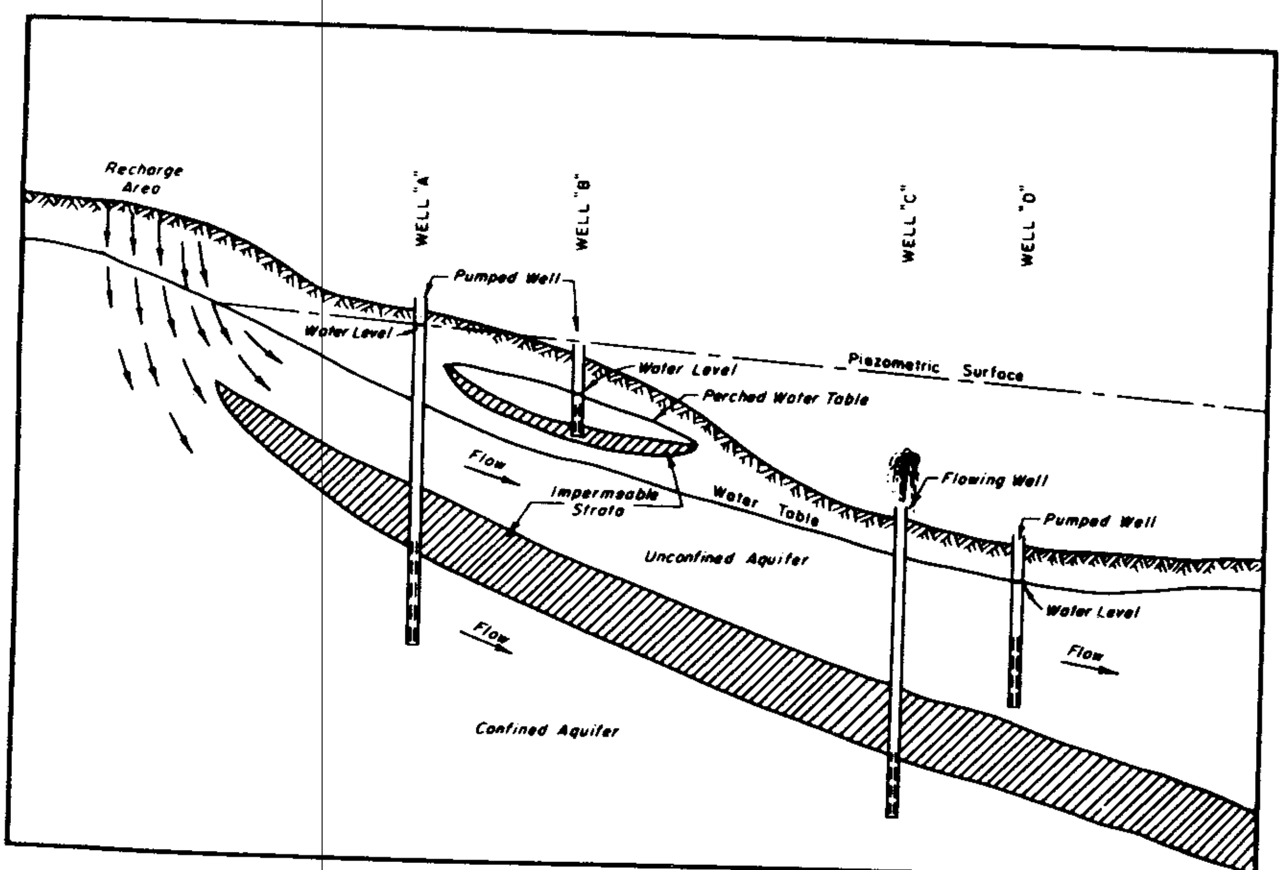
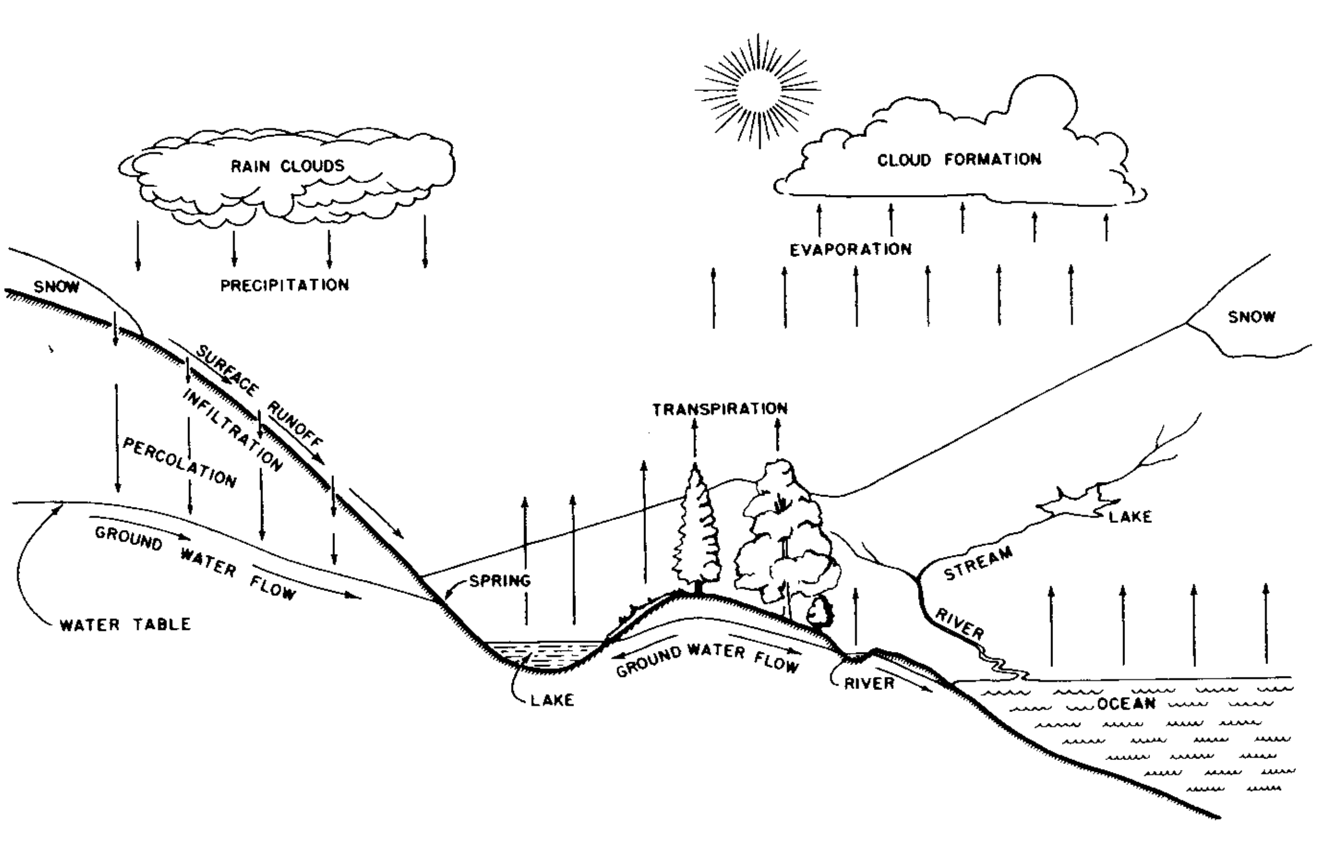


Figure 5 UNCONFINED AND CONFINED GROUND WATER

FIGURE 6



THE HYDROLOGIC CYCLE

surface runoff or infiltrates the ground water body. In time, runoff and ground water collect in bodies of water and the cycle begins anew.

The pattern of movement of a particle of water from the time it enters the ground to the time it emerges, either naturally or from a well, is controlled by the subsurface conditions encountered. Upon entering the ground, the particle of water moves downward through the zone of aeration and into the zone of saturation. This happens whenever water from precipitation, streamflow, applied irrigation, and all of the other various sources moves into the ground through the open spaces in permeable materials. The area over which this is accomplished is called a ground water recharge area. These areas may be found on mountains, along foothill slopes, and on valley floors. In Sonoma County, important recharge areas occur along the channel area of the Russian River. Here, the deposits are very permeable, allowing for the rapid infiltration of water down to the ground water body. Water flows over these recharge areas during the entire year, affording a continual replenishment to the ground water body.

Water which infiltrates the permeable material eventually reaches a zone of saturation. The water then moves under a hydraulic gradient into confined aquifers. Ground water under pressure moves laterally toward areas of lower pressure, such as pumping depressions. In cases where the pressure relief area is along a stream channel, springs form and help to maintain streamflow during periods of low precipitation.

The general ground water movement pattern of a valley can be interpreted from maps which show lines of equal elevation of the ground water surface. From such a map, the direction of ground water movement is interpreted as being perpendicular to the contour lines and moving from the higher elevation contour to the lower. The relative spacing between the contour lines indicates the hydraulic gradient of the ground water, which is an index of the resistance encountered as the water moves through the various permeable materials. Other physical barriers which may impede the movement of ground water are also indicated by the patterns or spacings of the ground water contours. The effect of faults on the movement of ground water can often be interpreted from the contour maps. Where faults have positioned a particular water-bearing stratum opposite an impermeable stratum, ground water may rise along the fault zone and appear at the ground surface as springs.

Water Well Numbering System

The water well numbering system used in this bulletin is based on the rectangular system of subdivision of public land. When Sonoma County was first settled, most valley lands became parts of 25 land-grant ranchos. Rancho names ranged from those of Miwok and Pomo Indian derivation, such as Petaluma (from "peta", place, and "yome", flat), to surnames such as Bodega (named for Spanish explorer Juan Francisco de la Bodega) and Spanish descriptive names, such as Agua Caliente (hot spring). Lands outside of the rancho land grants later became identified as public lands. These were later surveyed into townships of 36 square-mile area and referenced to the Mount Diablo Base and Meridian. Each township was divided into 36 sections of roughly one square-mile area. Because land-grant areas do not have township and section lines, these have been projected across for the purpose of numbering water wells.

A state well number has two basic parts, its township location and its section location. For example, Well No. 7N/8W-17G1 is located in Township 7 North, Range 8 West, and Section 17; this places the well west of Santa Rosa. Each section is subdivided into 16 quarter-quarter sections (40-acre tracts); these are identified by a letter designation. This particular well is in Tract "G", which also can be described as the southwest-quarter of the northeast-quarter of Section 17. The final number is the sequential number within that particular tract.

Physiography of Sonoma County

Sonoma County is situated in the Coast Ranges Geomorphic Province (refer to Appendix B for definitions of geologic, hydrologic, and related terms), which is characterized by northwest-trending mountains and valleys. The topography of the county ranges from low-lying mud flats along the north shore of San Pablo Bay, through which Petaluma Creek and Sonoma Creek move sluggishly, to Mount St. Helena, which frequently is mantled by snow in winter and has a crest elevation of 4,343 feet (1,324 meters). (Refer to Appendix C for English-Metric conversion tables.) Major mountain areas include the Mayacmas Mountains-Mount St. Helena-Sugarloaf Ridge zone, which forms the eastern boundary with Napa County, the Sonoma Mountains which separate the Santa Rosa Plain and Sonoma Valley, the rugged mountainous area between Healdsburg and the coast, and the low, rolling hills west of Sebastopol.

Six major valley areas contain the principal population centers of the county. In the south part of the county are located Sonoma Valley, drained by Sonoma Creek, and Petaluma Valley, drained by Petaluma Creek; both of these streams are tributary to San Pablo Bay. To the north are the valleys of the Russian River watershed. These include Cloverdale Valley, Alexander Valley, Dry Creek Valley, and the Santa Rosa Plain. Smaller valley areas include Rincon Valley, Kenwood Valley, and Bennett Valley, all tributary to Santa Rosa Plain, and Knights Valley and Franz Valley, which are tributary to the Russian River.

Geologic History of Sonoma County

The known geologic record in Sonoma County begins with rocks which date back to the middle of the Jurassic Period, or about 150 million years (m.y.) ago. Events which took place during the hundreds of millions of years preceding this period have been obliterated by later geologic conditions. During the some 125 million years from the Jurassic Period to the middle of the Tertiary Period, the area now known as Sonoma County was a part of the sea floor. At times this floor was covered by many thousands of feet of water teeming with all varieties of marine life. This sea floor continually received sediments from neighboring lands to the east; all the while, at depths of several miles, vast masses of molten magma slowly migrated upward to solidify as crystalline rock.

Near the end of the Miocene Epoch (12 m.y. ago) forces deep within the earth began forming what are now the mountains of northwestern California. These forces brought the ocean floor above sea level and exposed the sediments to wind and rain, where erosion shaped mountains and valleys. Continued mountain-building caused periods of widespread faulting which resulted in the displacement of several thousands of feet of formerly adjacent sediments. During the Pliocene Epoch (2 to 12 m.y. ago), much of what is now Sonoma County was above sea level. The topography was one of low, rolling hills with many lakes occupying valley areas. The lakes abounded with life, particularly microscopic plants called diatoms.

Near the close of the Pliocene Epoch (2 m.y. ago), volcanic activity broke out to the east. Many volcanic vents and cinder cones spewed out volumes of lava and ash as eruption after eruption took place. By the close of this activity, a broad volcanic highland had been formed along what is now the eastern boundary of the county. To the northwest, near what is now the town of Annapolis, there was a long, low, northwesterly-trending valley which was slowly being filled with soft, sandy sediments. Similar materials also were being deposited farther south on the plains which sloped gently from the volcanic highlands to the sea.

Once again, mountain building forces came into play, and the long valley near Annapolis was slowly elevated until only its remnants are seen today along the ridgetops. Meanwhile to the south, geologic forces were shaping Sonoma and Kenwood Valleys. To the west, however, were still rolling hills, and no evidence of the Santa Rosa Plain could be seen. About one m.y. ago, during the Pleistocene Epoch, a syncline began to develop west of Sonoma and Kenwood Valleys. Continued arching of the sediments eventually created the Santa Rosa Plain. Toward the close of this epoch, sea level stood about 300 feet (91 meters) lower than it does today because of the vast volumes of water locked in the glaciers of the great ice ages. Drainage from the Santa Rosa Plain originally flowed south toward San Pablo Bay, but uplift near Penngrove blocked this southward drainage. Subsequently, drainage turned toward the Russian River, which continues to carve a westward course across the Coast Ranges.

Geologic Formations and Their Water-Bearing Properties

Nearly all of the geologic formations of Sonoma County yield water to wells. Well yields range from 1,000 gallons per minute (gpm), or 3,800 liters per minute (l/m), in wells completed in coarse-grained alluvial materials to less than 1 gpm (3.8 l/m) in wells completed in consolidated rocks. Wells with high yields usually produce water of good to excellent quality; those of markedly lower yields may produce water containing significant quantities of undesirable mineral constituents.

Appendix D to this bulletin presents a detailed discussion of the ground water geology of Sonoma County. Included in the appendix is a discussion of the geologic history of the area as it affects ground water, a discussion of each geologic formation along with its water quality and water yielding characteristics, and finally a discussion of the geologic structure of Sonoma County and its effect on ground water quality and movement.

Data on the physical and water-bearing characteristics of each geologic unit in Sonoma County is summarized on Table 1. The surficial extent of each geologic unit is presented on Plate 1; their subsurface extent is shown in the geologic sections which appear in Figure 7. Water quality data for the various geologic units appear on Table 2, and well yield data appear on Table 3.

Table 1

GEOLOGIC FORMATIONS OF SONOMA COUNTY

Geologic Age		Geologic Formation	Stratigraphic Thickness (feet)	(meters)	Physical Characteristics	Water-Bearing Characteristics
QUATERNARY	HOLOCENE	Bay Mud Deposits	0 - 200+	0 - 60+	Organic clay, silt, and fine sand; peat may be present.	Contains sodium chloride ground water; of very low permeability.
		Sand Deposits	10 - 100+	3 - 30+	Unconsolidated to semiconsolidated eolian sand.	Dunes have excessive permeability. May contain sodium chloride water.
		Stream Channel Deposits	10 - 100+	3 - 30+	Unconsolidated coarse sand and gravel occurring along Russian River and other streams.	Highly permeable; transmissivities on the order of 850,000 gpd (10,540 m^2/day). Quality of water generally excellent.
		Landslides	to 200+	to 60	Unconsolidated masses of clay, rubble, and rock debris in a state of nonequilibrium.	Of low permeability. May contain ponds in head area; springs and seeps may occur at toe area.
		Younger Alluvium	30 - 300	10 - 90	Unconsolidated deposits of sand, silt, and clay with stringers of gravel.	Provides adequate quantities of ground water for domestic uses. Well yields range from 10 to 130 gpm (38 to 493 l/min) depending on location. Water is of excellent quality.
	PLEISTOCENE	Alluvian Fans	50 - 300+	15 - 90+	Unconsolidated deposits of sand, clay, and gravel deposited by streams draining mountains.	May provide adequate quantities of water for most uses depending on location of well. Well yields range up to 600 gpm (2,274 l/min). Quality of water is excellent.
		River Terrace Deposits	10 - 200+	3 - 60+	Unconsolidated deposits of sand, gravel, silt, and clay. Usually at higher elevation than adjacent river.	Reported well yields range from 10 to 60 gpm (38 to 227 l/min). Smaller terraces may contain little ground water unless underlain by water-bearing materials.
		Marine Terrace Deposits	25 - 50	8 - 15	Poorly consolidated deposits of silt, sand, and gravel.	Not a reliable source of ground water. Many terraces are thin and are drained; a few may yield small quantities of ground water to wells.
		Older Alluvium	50 - 500	15 - 150	Semiconsolidated lenticular beds of silt, clay, sand, and gravel; hardpan may be present.	Not a prolific producer of ground water. Wells reportedly yield from less than 1 to 30 gpm (4 to 114 l/min). Quality of ground water is excellent.
		Huichica Formation	900+	275+	Beds of reworked tuff, volcanic clay, and silt; pumice fragments in basal portion.	A poor producer of ground water. Well yields range from 10 to 100 gpm (38 to 380 l/min) with drawdowns as much as 250 feet (75 m). Water quality is not as good as in overlying materials; excessive sodium ion is present.
		Glen Ellen Formation	3,000	900	Beds of consolidated clay, silt, sand, and gravel; lignite also is present. Some beds of coarse conglomerate occur.	Highly variable in water-yielding capability. In Santa Rosa Plain, well yields are in range of 15 to 40 gpm (57 to 152 l/min); Sonoma Valley wells yield somewhat less. Wells to 800 feet (240 m) in depth yield good quality water; nitrate ion may be present. Wells deeper than 800 feet (240 m) yield poorer quality water.
TERTIARY	PLIOCENE	Merced Formation	50 - 1,000+	15 - 300+	Beds of fine-grained sandstone; shell beds are common. Some beds of claystone and volcanic material.	A principal water producer in Sonoma County. Wells produce from 20 to over 1,000 gpm (76 to over 3,785 l/min); drawdowns are usually 10 to 150 feet (3 to 45 m). Ground water usually is of excellent quality; excessive iron and manganese may be present.
		Ohlson Ranch Formation	20 - 160	6 - 50'	Sandstone, siltstone, and conglomerate.	Well yields range from 2 to 36 gpm (8 to 136 l/min); some wells go dry in fall months. The quality of water is excellent.
		Sonoma Volcanics	1,000+	300+	Mixed volcanic materials consisting of flows, dikes, plugs, and beds of andesite, rhyolite, basalt, tuff breccia, and tuff. Diatomite and black volcanic sandstone also present.	Well yield is highly variable. Most igneous rocks are nonwater-bearing; certain zones will produce from 10 to 50 gpm (4 to 190 l/min). Volcanic sediments may produce up to 50 gpm (190 l/min). Standing water levels may be as much as 300 feet (90 m) deep. Water quality usually is excellent; boron concentrations to 1 mg/l have been reported
		Petaluma Formation	4,000+	1,200+	Deformed beds of claystone, shale, sandstone, and lesser amounts of conglomerate and limestone.	Not a prolific producer of good quality water. Many wells yield less than 10 gpm (38 l/min). Ground water ranges from an excellent sodium bicarbonate to a sodium and calcium chloride water having conductivities up to 900 micromhos.
	PALEOCENE to MIOCENE	Tertiary Marine Sediments	1,000+	300+	Sandstone and mudstone along coast; sandstone and pebbly conglomerate at east edge of county. Of marine origin.	Wells along coast yield from 0.2 to 37 gpm (0.7 to 140 l/min) of moderately hard calcium bicarbonate water.
CRETACEOUS		Dry Creek Conglomerate	5,000+	1,500+	Indurated conglomerate composed of well-rounded cobbles and boulders in arkosic sand matrix. Of marine origin.	Wells yield from 20 to 60 gpm (76 to 227 l/min) with drawdowns to 105 feet (32 m). Ground water is an excellent quality calcium bicarbonate water.
JURA-CRETACEOUS		Franciscan Formation and Great Valley Sequence, Undifferentiated	20,000+	6,000+	Sandstone, graywacke, mudstone, greenstone, conglomerate, chert, and limestone, all highly sheared, veined, and faulted. Of marine origin.	Well yields range from 0.2 to 68 gpm (0.7 to 258 l/min). Water levels are as deep as 160 feet (48 m). Many springs are present in outcrop area. Ground water ranges from excellent quality at wells and cold springs to highly mineralized at thermal springs.
		Serpentine	?	?	Major bodies of sheared and faulted serpentine and related ultramafic rocks.	May yield small quantities of ground water. Water may be highly mineralized.
		Granitic Rocks	?	?	Deeply weathered quartz diorite occurring at Bodega Head.	Some ground water may be present in fractures. The quality may be acceptable for domestic use.

SUMMARY OF WATER

Geologic Formation	Area	Water Types	Range of Specific Conductance (micromhos)	Range of Total Hardness (mg/l)	Range of Total Dissolved Solids (mg/l)
Granitic Rocks	Bodega Head	Sodium Chloride	452	73	268
Franciscan Formation and Great Valley Sequence	Cloverdale	Calcium Bicarbonate	1230	445	685
	Petaluma	Sodium Bicarbonate	860	5	497
Dry Creek Conglomerate	Canyon Road	Calcium Bicarbonate	418	168	267
Petaluma Formation	Petaluma Valley	Sodium Bicarbonate and Sodium Chloride	601-1490	90-261	335-826
Sonoma Volcanics	Sonoma and Mayacmas Mts.	Sodium, Magnesium and Calcium Bicarbonate	211-559	74-139	108-315
Ohlson Ranch Formation	Annapolis	Sodium Bicarbonate	71-343	14-86	64-228
Merced Formation	Petaluma	Calcium Bicarbonate	308-978	139-390	230-592
	Sebastopol	Sodium Bicarbonate	91-584	6-128	93-440
	Occidental	Calcium Sulfate	427	149	296
Glen Ellen Formation	Santa Rosa Plain	Sodium and Magnesium Bicarbonate	214-484	29-164	197-322
	Alexander Valley	Sodium and Calcium Bicarbonate	350-551	18-114	222-400
Huichica Formation	Ramel Road	Calcium Bicarbonate	1780	182	810
Older Alluvium	Sonoma Valley	Sodium, Magnesium, and Calcium Bicarbonate	340-1040	30-202	169-610
	Lower Sonoma Valley	Sodium and Magnesium Chloride	455-7560	104-2460	318-4110
	Windsor	Sodium Bicarbonate	246-318	73-78	227-243
Marine Terrace Deposits	Salt Point	Sodium Bicarbonate	460	126	260
Alluvial Fans	Petaluma Valley	Sodium, Magnesium, and Calcium Bicarbonate	422-732	8-170	170-462
	Santa Rosa Valley	Sodium and Magnesium Bicarbonate	474-816	160-268	321-432
	Kenwood	Sodium Bicarbonate	351	102	262
Younger Alluvium	Sonoma Valley	Sodium and Magnesium Bicarbonate	401-923	28-226	217-574
	Petaluma Valley	Sodium, Magnesium, and Calcium Bicarbonate	340-927	24-355	232-570
	Lower Petaluma Valley	Sodium and Magnesium Chloride	5,260-25,250	630-8,862	3,060-15,272
	Kenwood	Sodium Bicarbonate	146	40	176
	Laguna de Santa Rosa	Sodium Bicarbonate	363	104	264
	Russian River	Sodium and Magnesium Bicarbonate	312-439	86-208	191-230
	Lower Russian River	Sodium Chloride	9,400	1,060	5,400
	Lower Salmon Creek	Sodium Chloride	342	208	206
	Dry Creek	Magnesium Bicarbonate	282-324	105-138	181-203
	Alexander Valley	Calcium Bicarbonate	317-385	151-195	189-195
Sand Deposits	Bodega Head	Magnesium Chloride	605	170	333
Bay Mud Deposits	Lower Petaluma Valley	Sodium and Magnesium Chloride	2,060-4,010	294-1,270	1,130-2,520
	Lower Sonoma Valley	Sodium Chloride	1,940-2,897	350-443	1,150-1,557

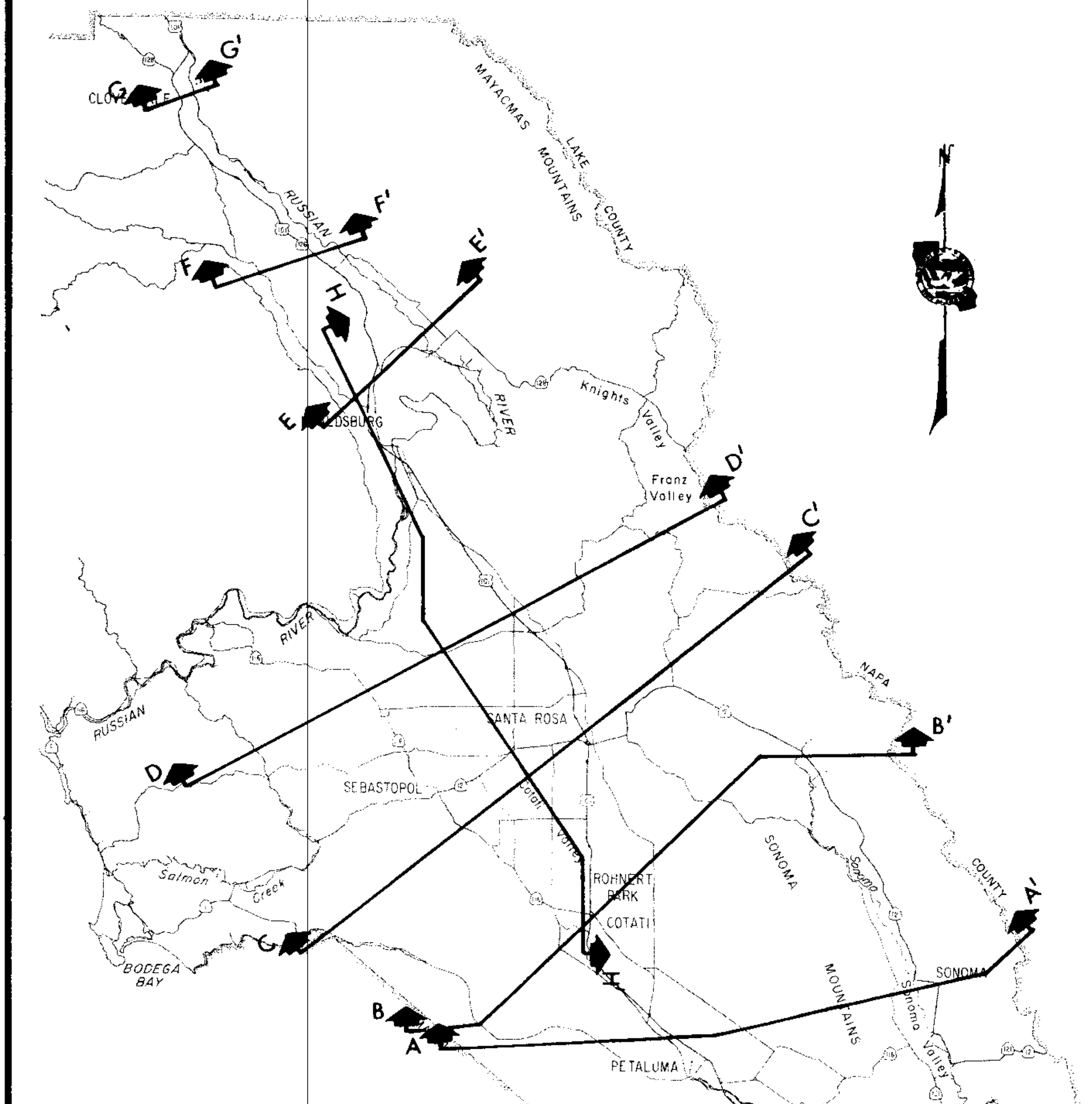
Range of Constituents (mg/l)						Range of Sodium Percentage	Remarks
Na^+	HCO_3^-	Cl^-	F^-	NO_3^-	B		
56	36	80	0.2	32	0.1	63	Spring-fed pond, abandoned nuclear power plant site
41	612	9.3	0.2	0	0.7	16	Alderglen Spring
185	318	60	1.7	0.4	0.8	99	Li = 0.05
20	188	7.9	0.6	0	0.1	20	As = 0; Li = 0.02
95-256	245-494	48-264	0.1-0.4	0.1-16.0	0.13-0.79	58-79	As: 0.0-0.03; Li: 0.03-0.06
7.4-75.0	126-260	2.3-46.0	0-0.5	0-11	0-0.54	14-59	As = 0; Li = 0.08
7.3-30.0	25-82	6.6-32.0	0.2-0.9	0-0.1	0	35-50	As = 0; Li: 0-0.06
11-40	163-240	9-130	0.2	1-27	0-0.12	14-18	Fe = 0.01-2.9
15-136	28-244	12-44	0-0.3	0.5-5.1	0-1.5	40-98	As=0; Pb=0; Mn: 0-0.01; Li: 0-0.01; Fe: 0.14-0.59
2.5	101	16	0.2	0.1	0.3	26	Fe = 2.2; Mn = 0.32
18-31	116-150	7-49	0.1-0.2	0.1-30.0	0.08-0.63	21-64	Fe = 0.04
32-118	206-287	15-33	0-0.8	0.5-0.8	0.12-0.32	37-91	Fe = 0.12
309	588	188	0.3	4.4	1.6	71	As = 0.01; Li = 0.04
10-172	128-366	2.4-139	0-1.2	0-47	0-1.4	29-87	As=0; Fe: 0-0.1; Mn=0.03; Li=0.04
49-585	0-90	86-2600	0-0.2	2-10	0.06-0.1	34-50	Affected by sea water intrusion
23-32	110-157	17-22	0.2-0.3	0-1	0.43-1.4	39-44	As=0.02; Pb=0; Fe=0.33; Mn=0.97; Li=0.05
38	132	62	0.1	0	0	39	As=0; Li=0.02
25-182	164-391	20-63	0-0.7	0-1	0-0.81	24-98	Fe: 0-0.1
41-57	222-329	25-58	0.1-0.2	0.1-21	0.07-0.33	32-35	
44	210	11	0.1	0	0.1	47	
20-211	204-488	1.5-71	0.1-0.5	0-1.5	0.21-4.4	16-94	Fe=0.10; Al=0.02; Zn=0.005
17-205	164-487	13-76	0-0.32	0.4-33	0-2.2	21-95	Fe = 0.02
925-2,480	122-506	1,360-9,420	0-0.5	1-15	1.01-2.5	38-76	Affected by sea water intrusion
14	79	4.8	0.2	0.2	---	39	Fe = 0.17
37	176	30	0.2	0	0	43	Fe = 0.02
8.8-30	156-243	8.4-14	0-0.1	0.6-5.5	0-0.5	8-41	Fe: 0.1-2.2; Li=0
1,620	165	2,920	0.1	3.8	0.13	75	Fe = 0.2; affected by sea water intrusion
32	76	48	0.1	12.0	1.4	46	As=0; Fe=0.02; Pb=0; Mn=0; Li=0
8.6-22	134-164	9-16	0-0.1	0-10	0.05-0.14	13-31	
8.5-10	170-218	5.8-8.4	0-0.1	0.8-16	0.18-1.8	9-13	
45	29	122	0	42	0.04	36	Fe = 0.02
333-368	531-572	381-1,090	0.2-0.6	2.5-13	0.27-0.92	36-70	Affected by sea water intrusion
298-428	369-597	321-656	0-0.4	17-20	2.0-2.11	64-67	Affected by sea water intrusion

Table 3

SUMMARY OF YIELD CHARACTERISTICS OF SELECTED WELLS

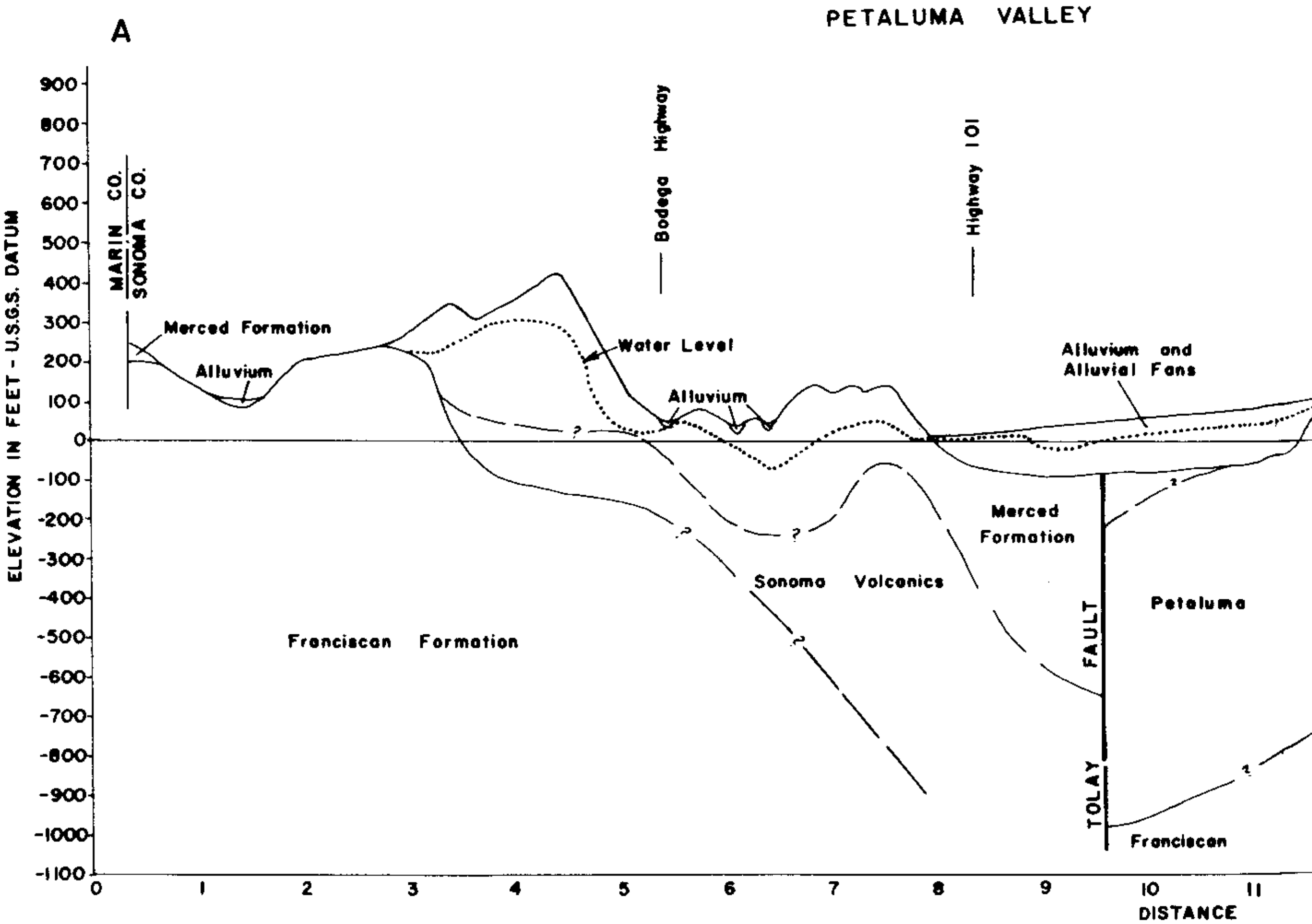
Geologic Formation	Number of Selected Wells	Range of Depth (feet)	Range of Discharge (gpm)	Range of Drawdown (feet)	Range of Specific Capacity a/ (gal/min/ft)	Range of Yield b/ (gal/min/ft)	Range of Depth (meters)	Range of Discharge (l/min)	Range of Drawdown (meters)	Range of Specific Capacity a/ (l/min/m)	Range of Yield b/ (l/min/m)
Jura-Cretaceous	27	20-257	0.2-68	13-135	--	0.01-1.5	*6-78*	*0.7-257*	*4-41*	--	*0.1-19*
Dry Creek Conglomerate	11	50-341	20-60	15-105	--	0.12-1.1	*15-104*	*76-227*	*5-32*	--	*1.5-14*
Tertiary Marine Sediments	8	124-300	0.2-37	74-265	--	0.001-0.33	*38-91*	*0.7-140*	*23-81*	--	*0.1-4*
Petaluma Formation	42	50-739	5-739	5-306	10-415	0.01-2.0	*15-225*	*19-2,797*	*3-126*	*8-210*	*0.1-25*
Sonoma Volcanics	33	128-1005	1.7-345	0-800	--	0.004-26.2	*39-306*	*6-1,306*	*0-244*	--	*0.06-324*
Merced Formation	49	62-480	20-1000	10-150	--	0.1-5.0	*19-146*	*76-3,785*	*3-46*	--	*1-63*
Ohlson Ranch Formation	5	90-197	3-36	30-125	--	0.02-1.8	*27-60*	*11-136*	*9-38*	--	*0.2-22*
Glen Ellen Formation	42	50-452	3-500	1-210	3.7	0.1-50.0	*15-138*	*11-1,893*	*0.3-64*	*462*	*1.2-624*
Huichica Formation	5	175-543	10-100	50-250	--	0.04-1.1	*53-166*	*38-379*	*15-76*	--	*0.5-14*
Older Alluvium	13	68-280	7-70	5-90	--	0.1-3.2	*21-85*	*26-265*	*1.5-27*	--	*1-40*
Terrace Deposits	12	48-125	12-800	1-60	--	0.2-133.0	*15-38*	*45-3,028*	*0.3-18*	--	*2.4-2,178*
Alluvian Fan Deposits	23	45-292	5-1000	6-170	--	0.1-14.7	*14-89*	*19-3,785*	*1.8-52*	--	*1.2-210*
Younger Alluvium	66	19-291	4-2000	1-180	--	0.3-40.9	*6-89*	*15-7,571*	*0.3-55*	--	*3.6-510*
Landslides	2	175-200	40-50	0	--	--	*53-61*	*151-1,893*	*0*	--	--
Stream Channel Deposits	23	18-171	110-3300	0.2-28	117	9-452	*5-52*	*416-12,491*	*0.1-9*	*1,452*	*111-5,610*
Bay Mud Deposits	1	30	1	19	--	0.1	*9*	*4*	*6*	--	*0.67*

a/ Based on pump test data. Reported as gallons per minute per foot of drawdown and *liters per minute per meter of drawdown.*
b/ Based on bailer test data. Reported as gallons per minute per foot of saturated materials and *liters per minute per meter of saturated materials.*



SECTION	SHEET
A–A'	1
B–B'	2
C–C'	3
D–D'	4
E–E'	5
F–F'	5
G–G'	5
H–H'	6

INDEX TO GEOLOGIC SECTIONS



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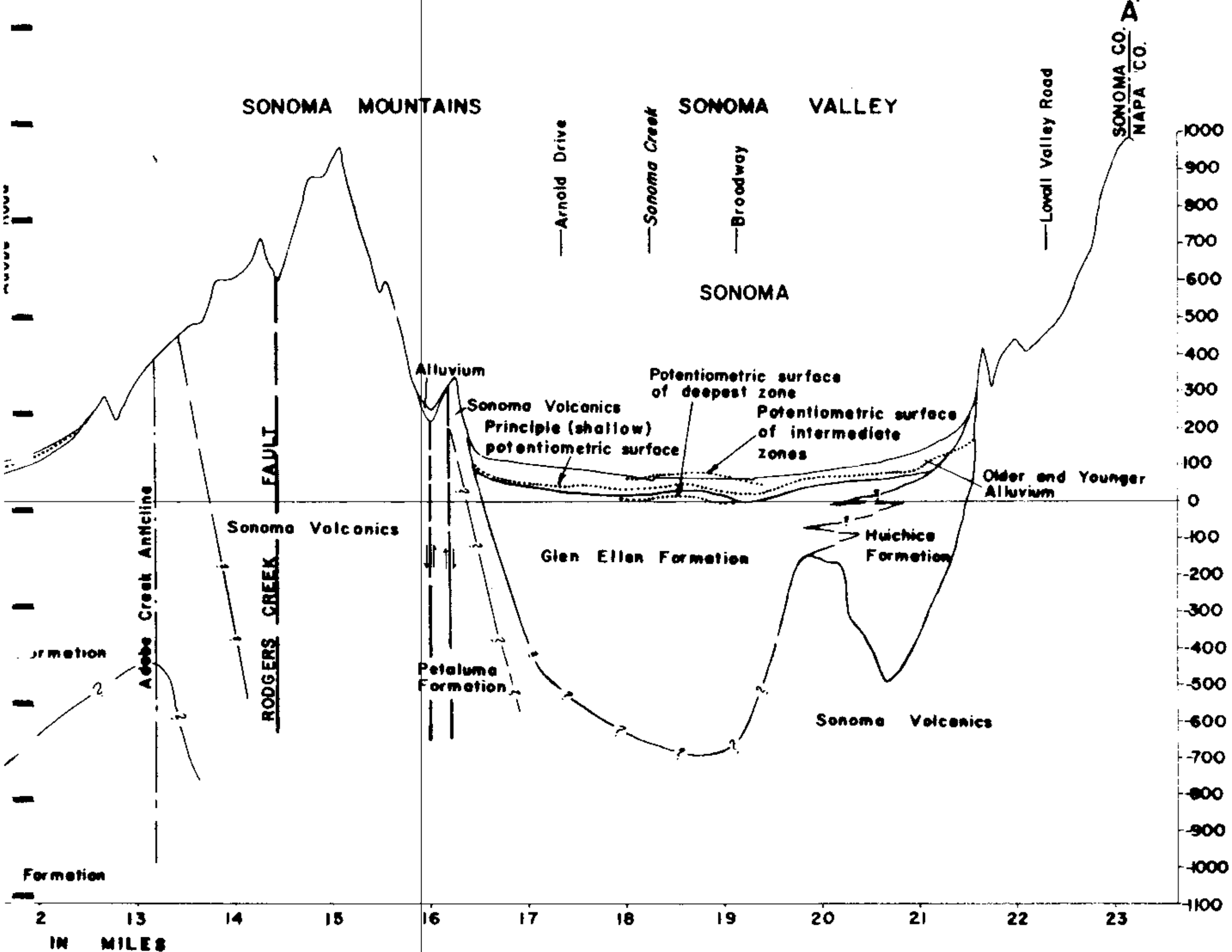

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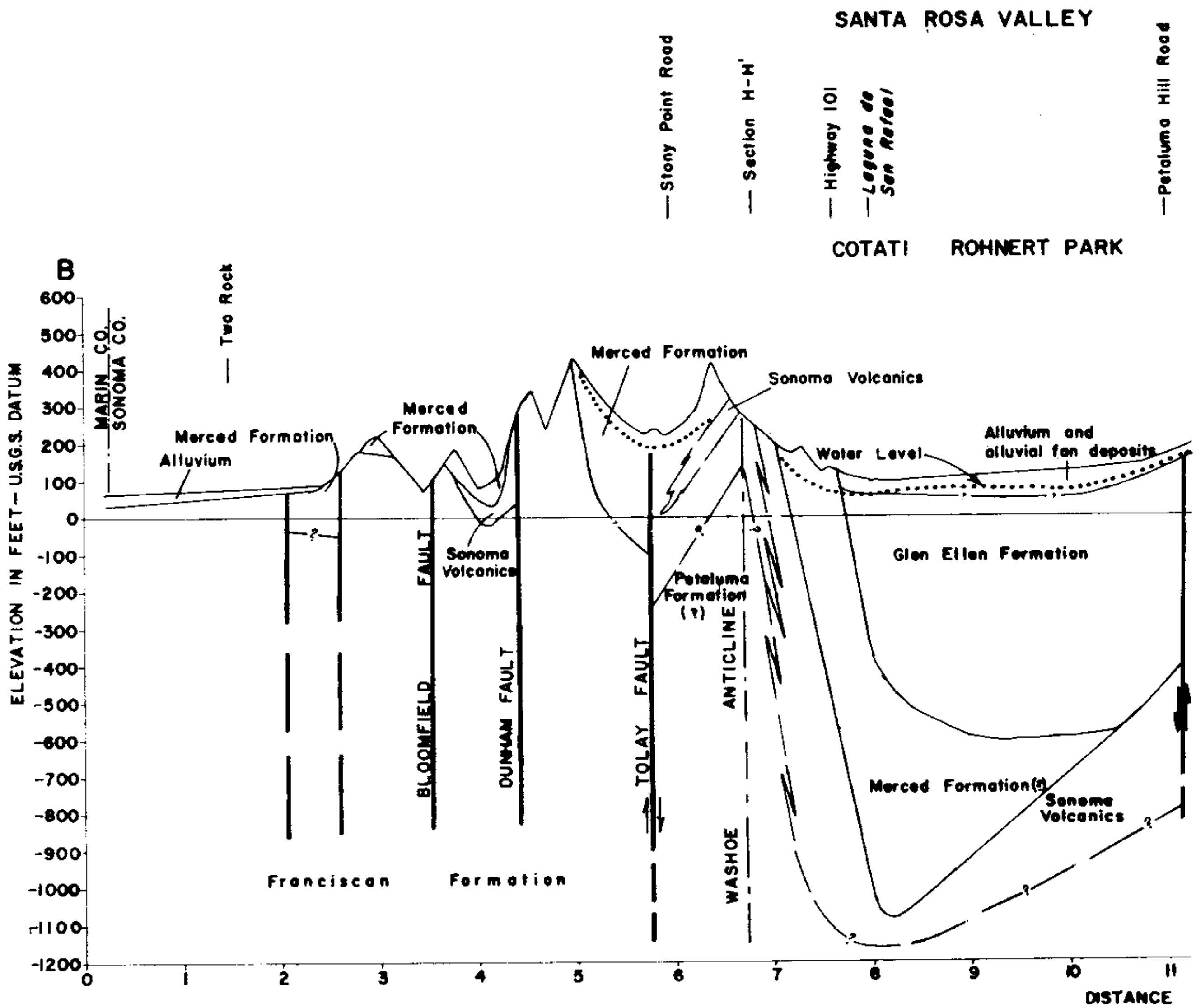

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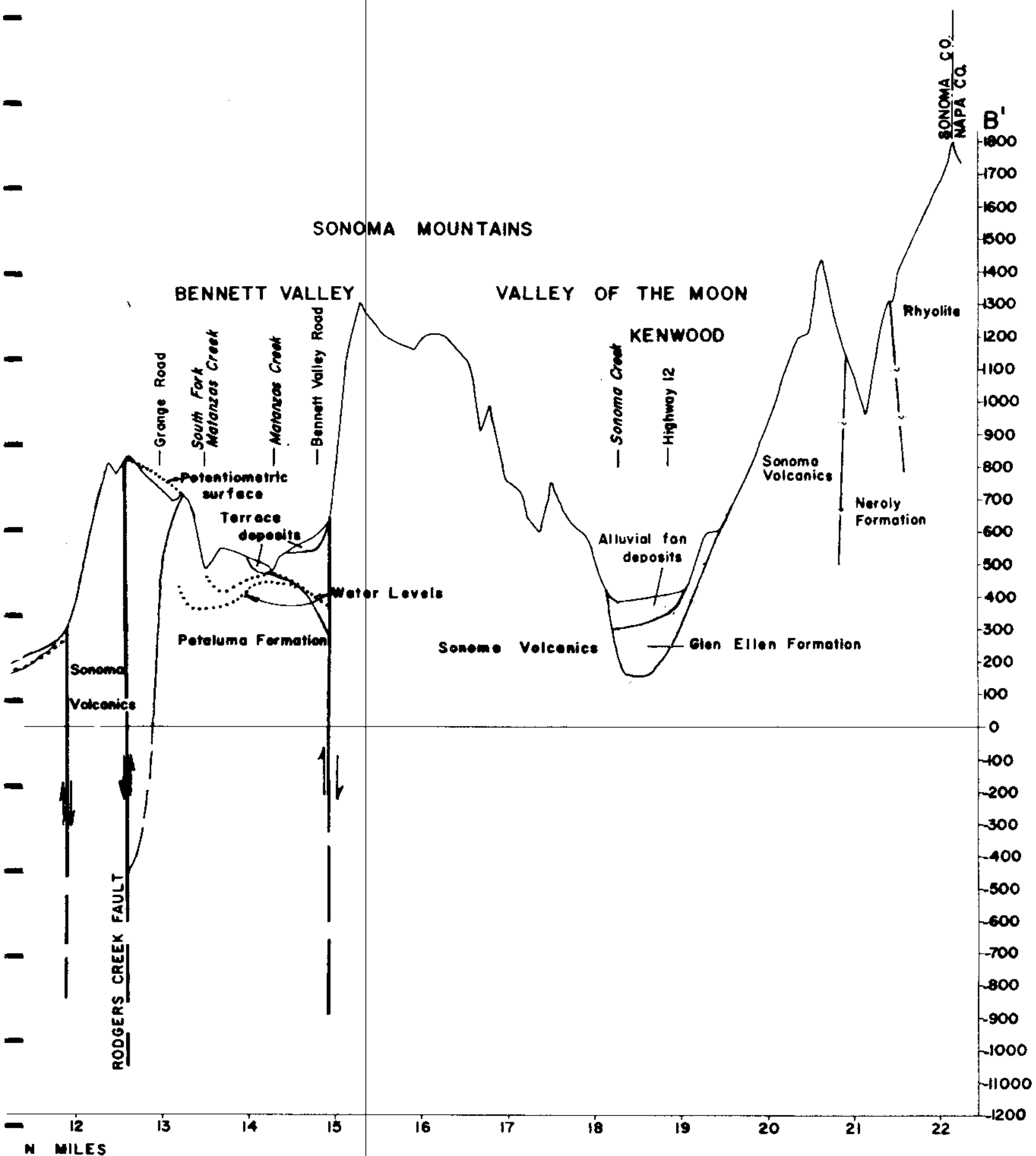

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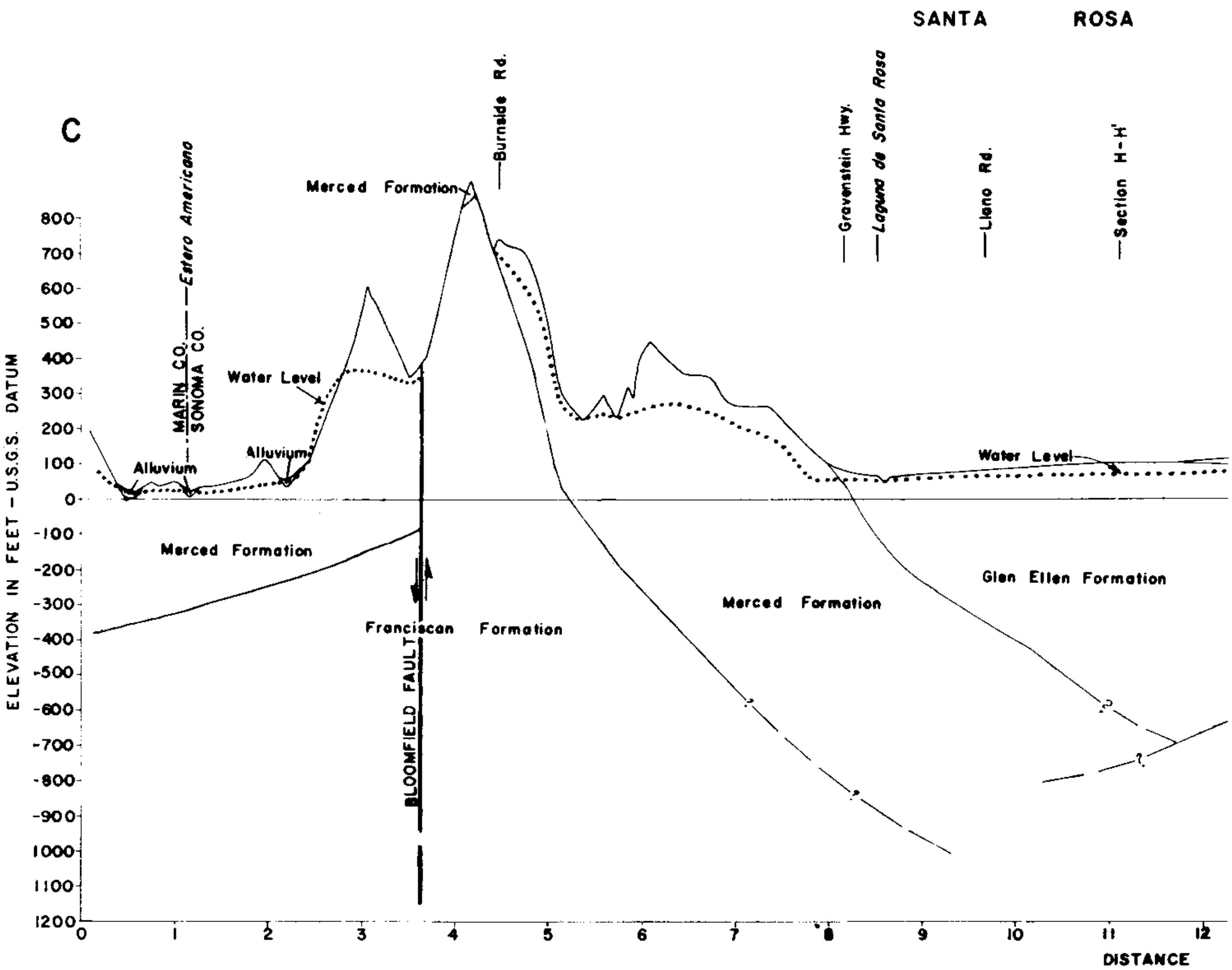

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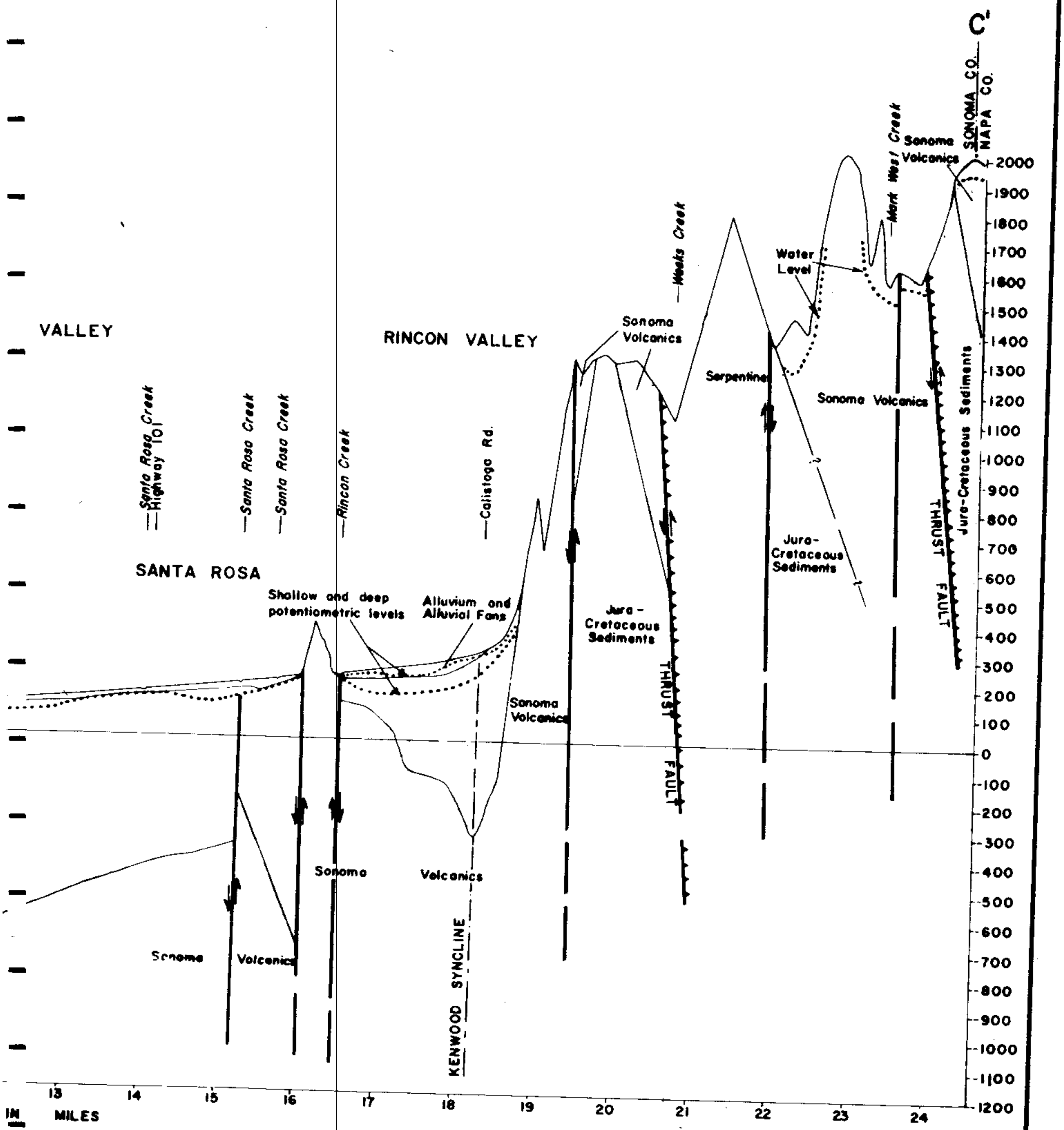

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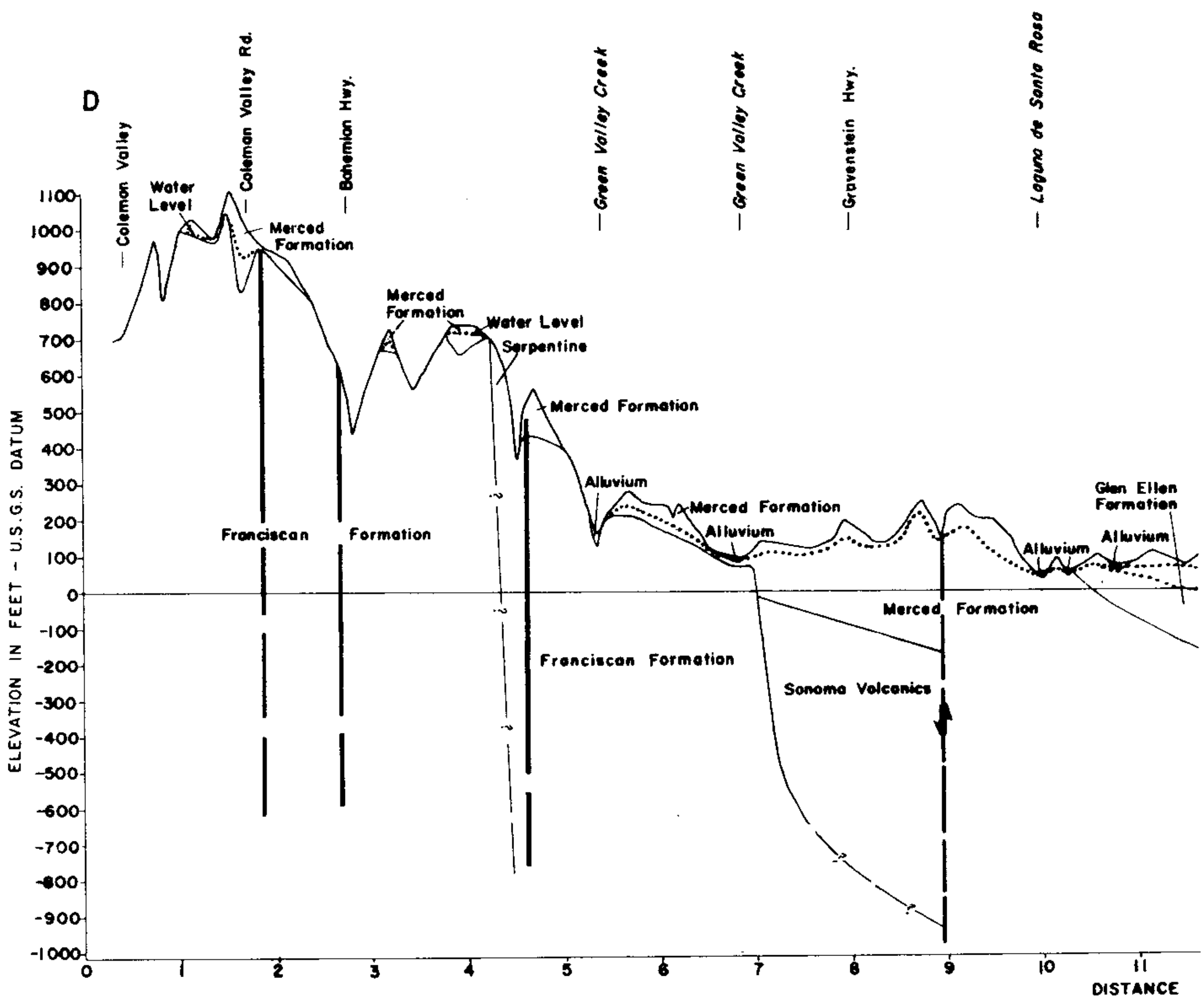

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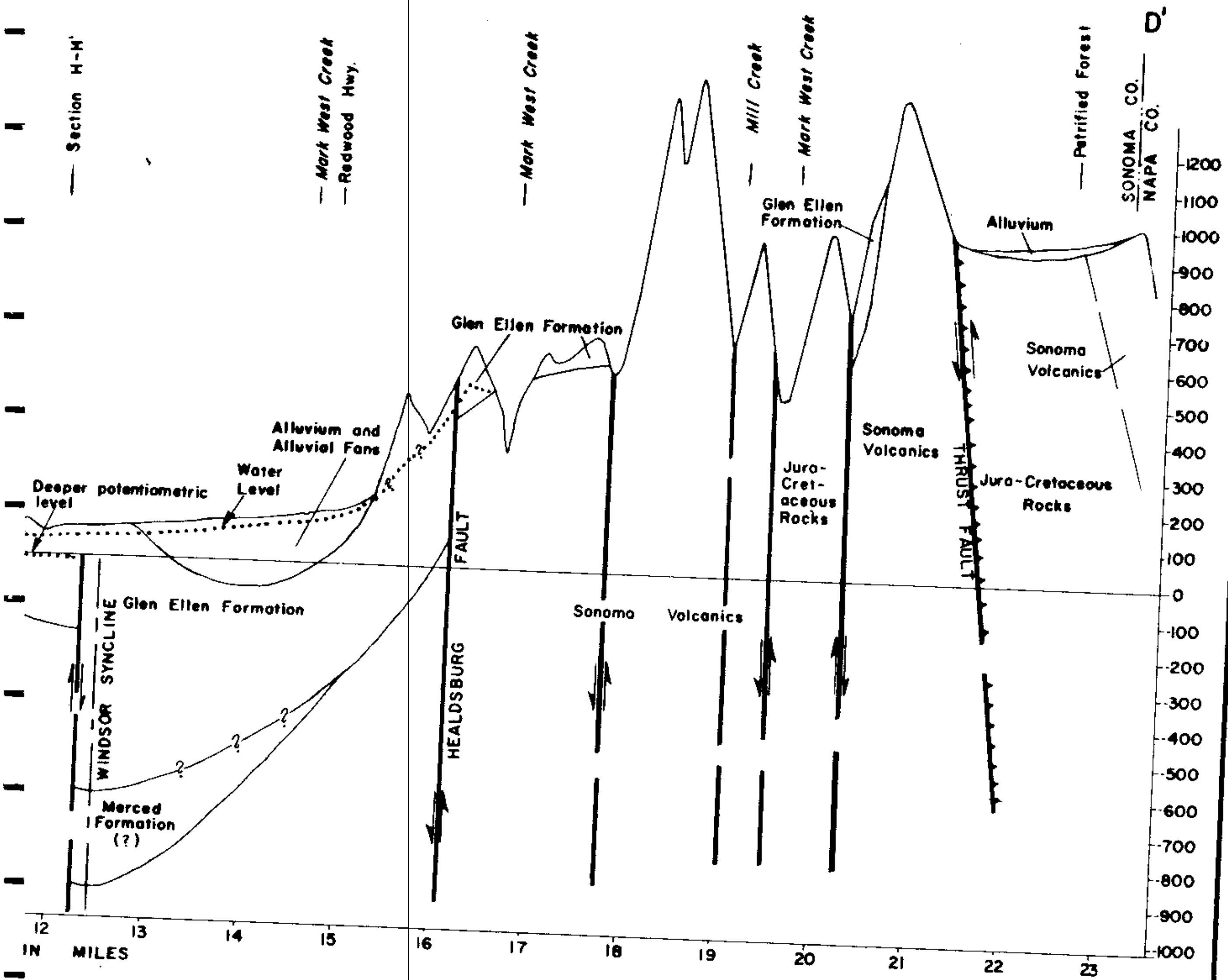

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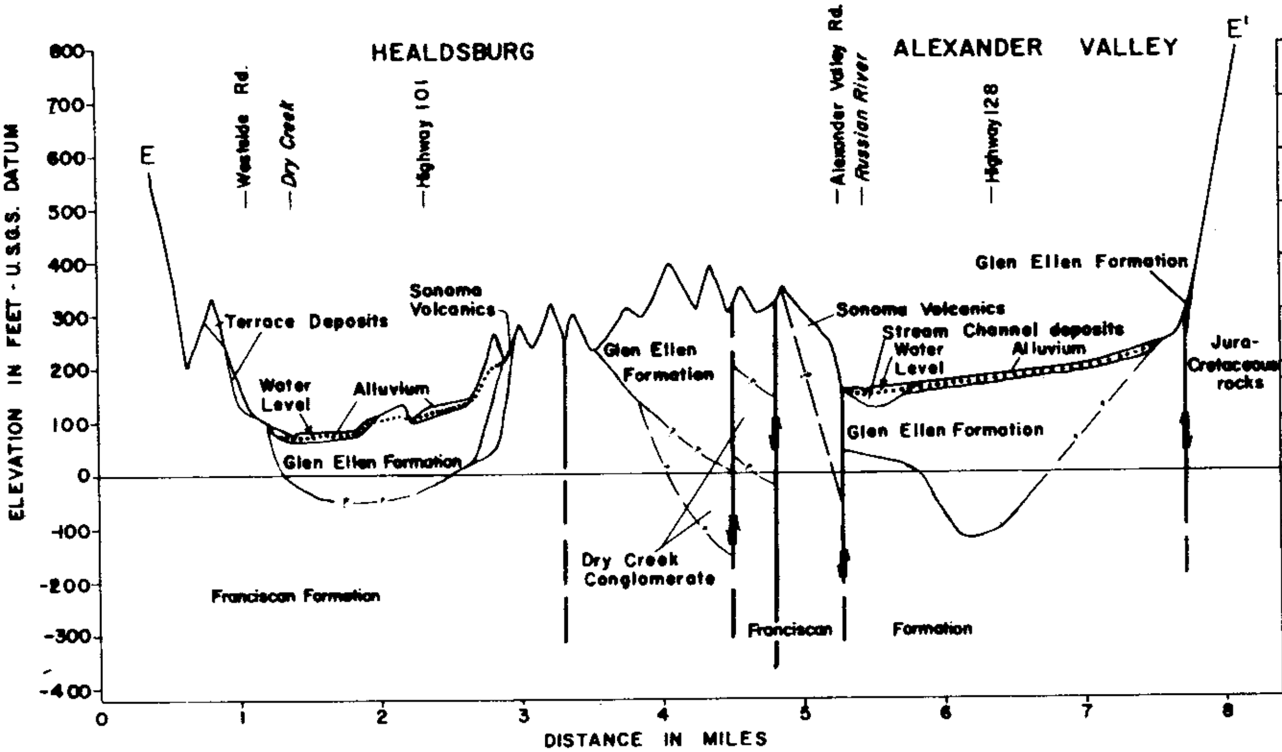

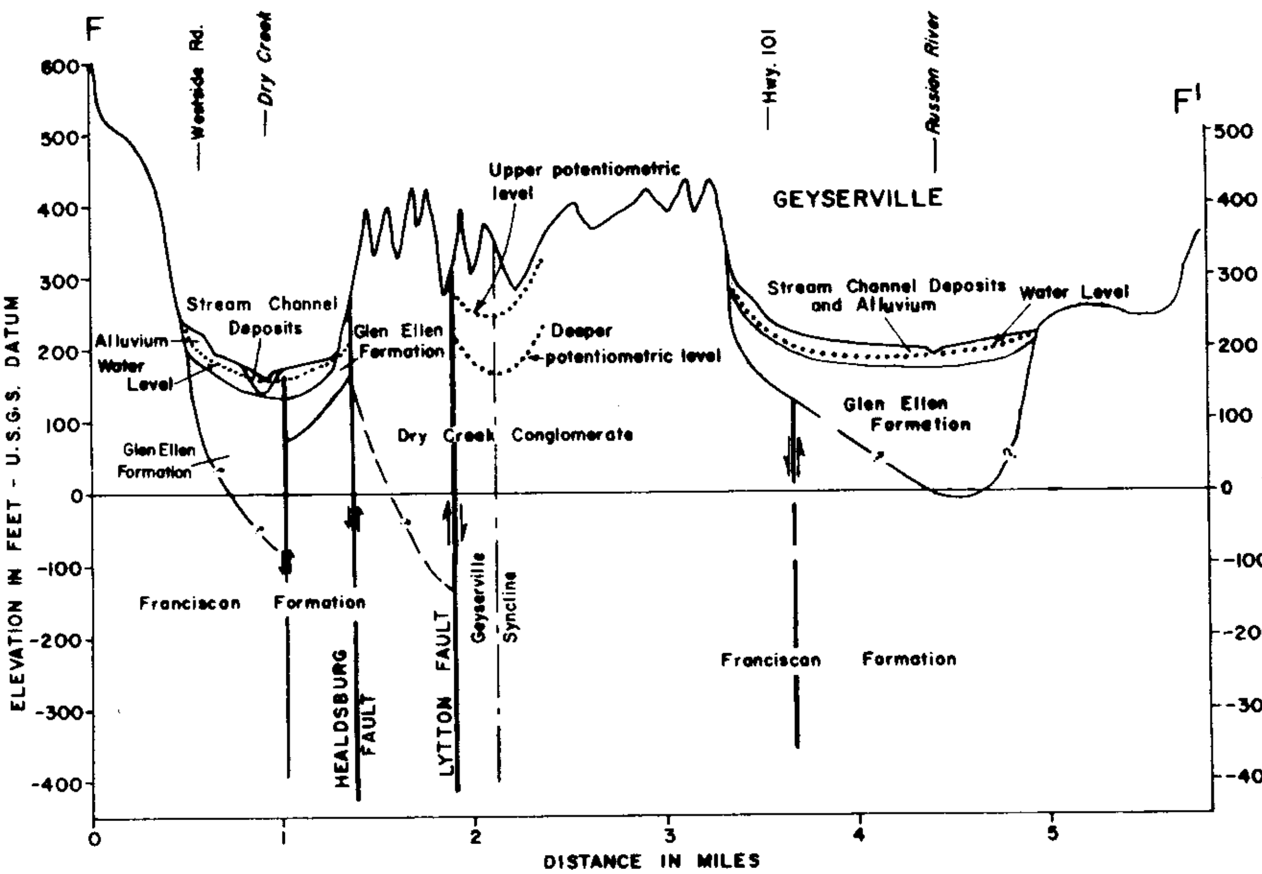

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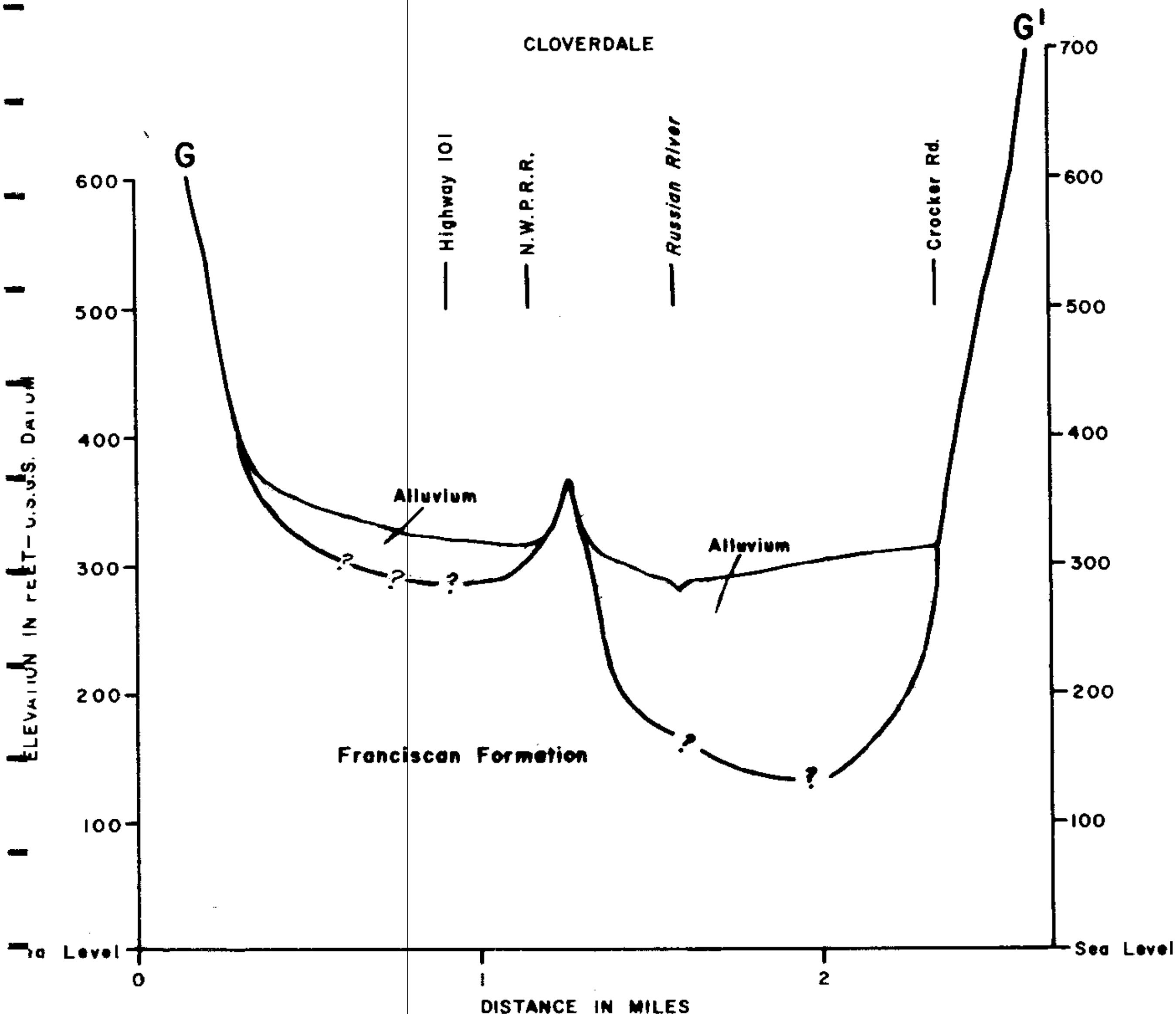

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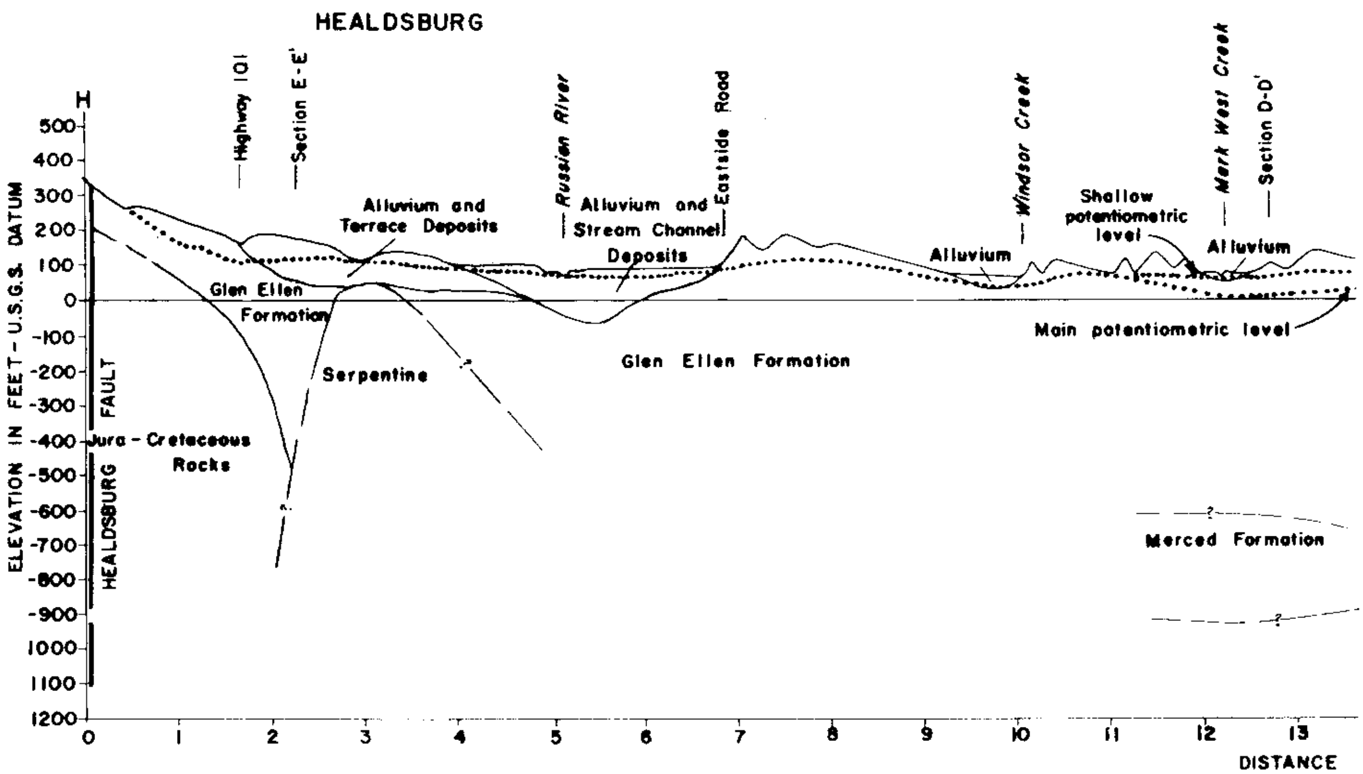

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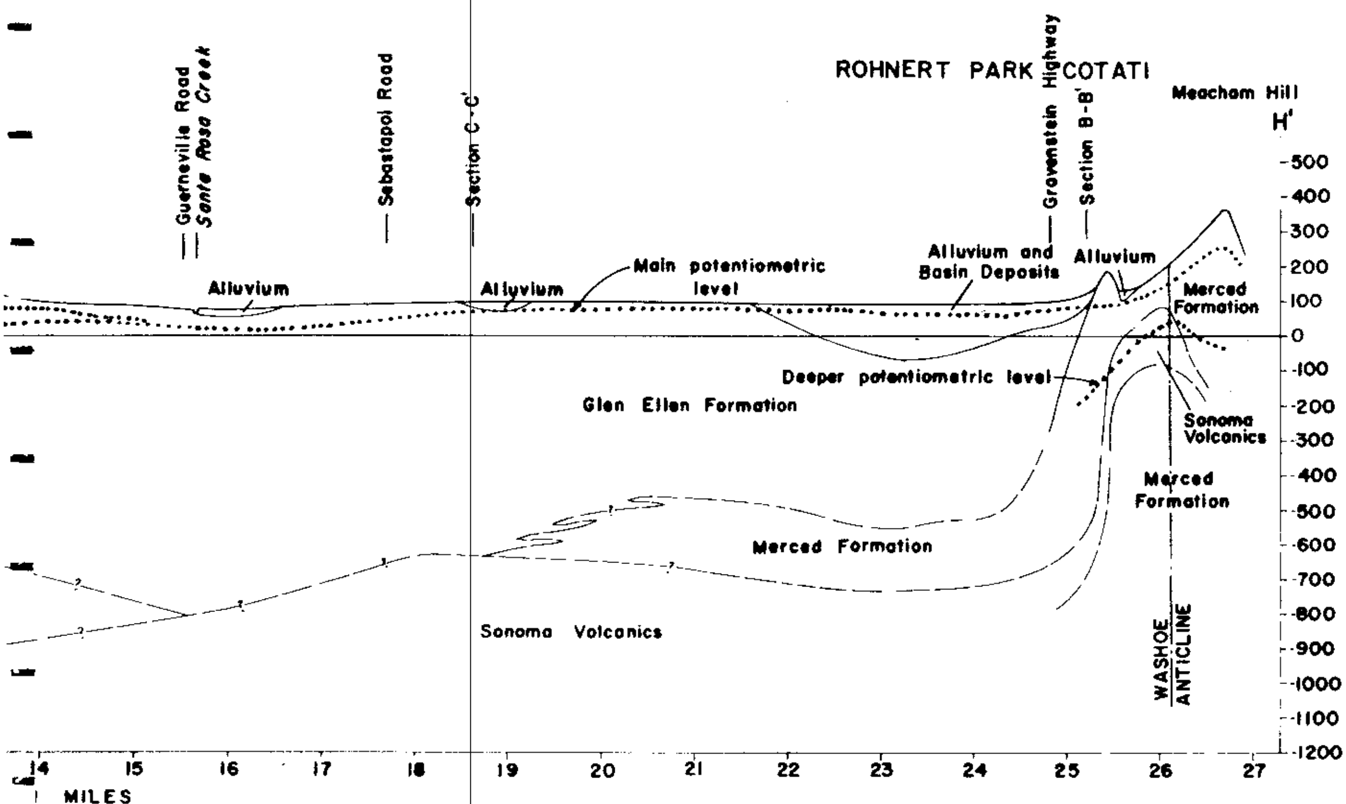


SONOMA COUNTY

CHAPTER III. WATER SUPPLY SYSTEMS

Water supply systems in Sonoma County are of two basic types: (1) multiple service connection systems served by surface and/or ground water; and (2) individual domestic wells. The first type is discussed below; the latter type is discussed in Chapter V.

In 1970, Sonoma County had a population of 204,885. Of this number, 99,171, or 48.5 percent, lived within the boundaries of incorporated cities and thus received piped water. Each of the eight incorporated cities in Sonoma County operates its own municipal water system. The total number of municipal service connections for these systems is 37,669, and the total annual water demand on these eight systems exceeds 20,000 acre-feet (24.6 cubic hectometers). This demand is met with ground water and also with surface water provided by the Sonoma County Water Agency.

Twenty-one commercial water companies operate in the county. These range from large municipal operations, such as at Guerneville, which has 3,100 service connections, to small systems having less than 50 service connections. The commercial systems rely principally on ground water, although some surface water is used; their total annual water demand is nearly 4,000 acre-feet (4.9 hm^3). The commercial systems have a total of 3,733 service connections.

There also are 112 other water systems in the county. These include one public utility district, three county water districts, 38 private water systems, 68 mutual water companies, and 50 mobile home park systems.

Data for all water systems in Sonoma County, except the mobile home park systems, are presented on Table 4. Data for the mobile home park systems are presented on Table 5. Figure 8 shows the present and proposed service areas for all water systems having greater than 150 service connections. Also shown on the figure are the locations of all small water systems (those with less than 150 service connections), as well as all mobile home park systems.

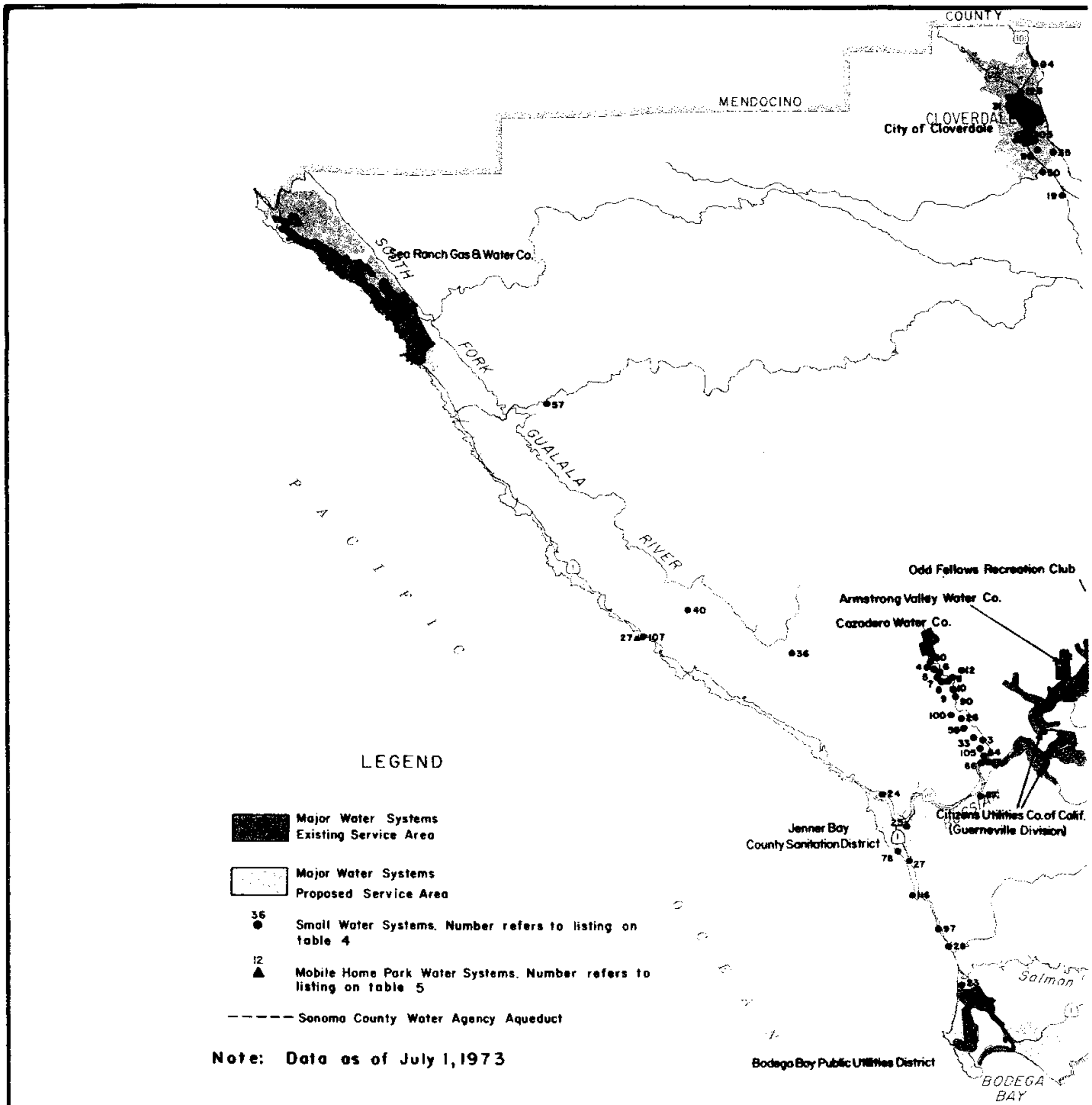
Table 4

WATER SYSTEMS IN SONOMA COUNTY

Name	Index[1/] Number	Type[2/]	Area Served	Number of Service Connections	Source of Water	Storage Capacity (gallons)	Annual Demand (million gallons)	Storage Capacity (cubic meters)	Annual Demand (cubic meters)
Alexander Valley Acres Mutual Water Co.	1	1	Alexander Valley	14	Well & Russian River	20,000	--	76	--
Armstrong Valley Water Co.		2	Guerneville	286	Wells	60,500	270[3/]	229	10^6
Athena Terrace Mutual Water Co.	2	1	Forestville	23	Well	24,000	--	91	--
Austin Acres Mutual Water Co.	3	1	Austin Creek	26	Well	Pressure System	--	--	--
Austin Creek Mutual Water Co. Blocks 1 & 2	4	1	Austin Creek	7	Well	1,200	--	4.5	--
Austin Creek Mutual Water Co. Blocks 3 & 4	5	1	Austin Creek	18	---	---	--	--	--
Austin Creek Mutual Water Co. Blocks 5 & 6	6	1	Austin Creek	10	Well	3,000	--	11	--
Austin Creek Mutual Water Co. Block 8	7	1	Austin Creek	3	Well	---	--	--	--
Austin Creek Mutual Water Co. Block 10	8	1	---	2	---	---	--	--	--
Austin Creek Mutual Water Co. Blocks 11 & 12	9	1	Austin Creek	5	Well	Pressure System	--	--	--
Austin Creek Mutual Water Co. Blocks 13, 14, & 15	10	1	Austin Creek	20	Well	1,000	--	4	--
Austin Creek Mutual Water Co. Blocks 17, 18, & 19	11	1	Austin Creek	15	Well	Pressure System	--	--	--
Austin Creek Mutual Water Co. Blocks 20 & 21	12	1	Austin Creek	17	Well	Pressure System	--	--	--
Austin Creek Mutual Water Co.	13	1	Mouth of Austin Creek	27	Well	50,000	--	189	--
Belglen Mutual Water Co.	14	1	Sebastopol	16	Well	---	--	--	--
Belmont Terrace Mutual Water Co.	15	1	Sebastopol	86	Well	40,000	--	151	--
Bennett Ridge Mutual Water Co.	16	1	Bennett Ridge	45	2 Wells	70,000	--	265	--
Black Mountain Conservation Camp	36	3	Black Mountain Camp	7	Springs	---	--	--	--
Bloomfield Mutual Water Co.	17	1	Sebastopol	6	Well	Pressure System	--	--	--
Bodega Bay Public Utilities District		4	Bodega Bay	279	Wells	250,000	--	946	--
Bohemian Grove Water System		3	Bohemian Grove	175+	Wells	500,000	--	1,893	--
Boucher Water System	19	3	Cloverdale	30	Well & Springs	65,000	--	246	--
Brand Water Co.	20	3	Santa Rosa	32	2 Wells	40,000	--	151	--
Branger Mutual Water Co.	21	1	Bennett Valley	74	Wells	50,000	--	189	--
Bressie Water System	22	2	Mirabel	130	2 Wells	30,000	--	114	--
Bressie Water System	23	2	Salmon Creek	90	Well	32,000	--	121	--
Bressie Water System	24	2	Jenner	115	Reservoir	30,000	--	114	--
Bridgehaven Resort	25	3	Bridgehaven	10	Springs & Creek	---	--	--	--
California State College, Sonoma		3	State College	---	Wells	4,200,000	--	15,900	--
Camp Meeker Water System, Inc.		2	Camp Meeker	355	Wells	154,000	--	583	--
Camp Thayer	26	3	Austin Creek	22	Well	10,000	--	38	--
Cannon Manor Water Service	18	3	Petaluma Hill Road	18	Well	30,000	--	114	--
Carmel-by-the-Sea Mutual Water Co.	28	1	Carmel-by-the-Sea	72	2 Springs	60,000	--	228	
Case and Wolf Water System	27	3	Wrights Beach	11	---				
Cazadero Water Co.		2	Cazadero	145	Wells	134,000	210[3/]	507	$0.79X10^6$
Chapultepec Mutual Water Corp.	30	1	Lichau Road	0 Present 25 Maximum	2 Wells	Pressure System	--	--	--
Citizens Utilities Co. of Calif.									
Guerneville Division		2	Guerneville, Monte Rio, Guerneville Park, Rio Nido, Vacation Beach, Villa Grande, Montesano	3100	Wells, Springs	134,000	100[3/]	507	$0.38X10^6$
Larkfield Division		2	Larkfield	633	Wells, SCWA[4/]	235,000	182	890	$0.69X10^6$

Table 4 (continued)

Name	Index1/ Number	Type2/	Area Served	Number of Service Connections	Source of Water	Storage Capacity (gallons)	Annual Demand (million gallons)	Storage Capacity (cubic meters)	Annual Demand (cubic meters)
College Park Mutual Water Co.	32	1	Cold Springs Rd.	43	Well	87,000	--	329	--
Clover Crest Water Co.	31	3	Cloverdale	12	Cloverdale Water Dept.	8,000	--	30	--
Cloverdale Water Department		5	Cloverdale	1200	Wells	770,000	212	2,916	$0.8X10^6$
Cotati Water Department		5	Cotati	662	SCWA4/	105,000	29	398	$0.1X10^6$
Creekwood Acres Water Service	33	3	Cazadero	12	Spring	12,000	--	45	--
Diamond A Mutual Water Co.	34	1	Diamond A Estates	75	2 Wells	80,000	--	303	--
Dusche Water Co.	35	3	Cloverdale Rancheria	10	2 Wells	Pressure System	--	--	--
End-O-Valley Mutual Water Co.	37	1	Rincon Valley	30	Well	Pressure System	--	--	--
Fairview Court Mutual Water Co.	38	1	Petaluma	---	---	---	--	--	--
Fir Crest Mutual Water Co.	39	1	Sebastopol	42	2 Wells	15,000	--	57	--
Fitch Mountain Water Supply		5	Fitch Mountain	325	Wells, City of Healdsburg	76,000	--	258	--
Forestville County Water District		6	Forestville	400	SCWA4/	700,000	--	2,650	--
Fort Ross Highlands Mutual Water Co.	40	1	Seaview Road	42	Well	---	--	--	--
Franz Hill Mutual Water Co.	41	1	Franz Valley Road	3-6	Well	15,000	--	57	--
Freestone Mutual Water Co.	42	1	Freestone	18	Spring	100,000	--	379	--
Garfield Water System	43	3	Porter Creek Road	5	Well	15,000	--	57	--
Geyserville Water Works		2	Geyserville	175	Wells	75,000	--	284	--
Gill Creek Mutual Water Co.	44	1	Geyserville	107	Well, Spring	30,000	--	114	--
Hacienda Water Co.		2	Hacienda	150	Wells	55,000	--	208	--
Happy Acres Water Co.	45	3	Stony Point Road	11	Well	10,000	--	38	--
Haub Heights Mutual Water Co.	46	1	Healdsburg	16	Well	10,000	--	38	--
Hawkins Water Service	47	3	Santa Rosa	35	Well	---	--	--	--
Healdsburg Water Dept.		5	Healdsburg	2035	Wells	4,574,000	--	17,314	--
Heights Mutual Water Co.	49	1	Santa Rosa	2	Well	42,000	--	159	--
Hess & Billway Water System	48	3	Santa Rosa	8	2 Wells	Pressure System	--	--	--
Hiatt Mutual Water Co.	50	1	Cloverdale	6	2 Wells	12,000	--	45	--
Hilton Mutual Water Co.	51	1	Hilton Resort	20	---	---	--	--	--
Holland Hts. Mutual Water Co.	52	1	Forestville	92	4 Wells	55,000	--	208	--
Hollydale Mutual Water Co.	53	1	Forestville	5	Well	20,000	--	76	--
Hopkin Water System	54	3	Sonoma Mt. Road	2	Springs	5,000	--	19	--
Huckelberry Heights Mutual Water Co.	55	1	Cazadero	32	Well	50,000	--	189	--
Jaylee Heights Mutual Water Co.	56	1	Santa Rosa	7	Well	15,000	--	57	--
Kashia Indian Reservation Water Co.	57	3	Kashia Reservation	---	---	---	--	--	--
Kelly Mutual Water Co.	58	1	Sebastopol	42	Well	30,000	--	114	--
Kenwood Mutual Water Co.	29	1	Kenwood	111	Well	10,000	--	38	--
Lancaster Water Co.	59	3	Santa Rosa	6	Well	30,000	--	114	--
Larkin Woods Mutual Water Co.	60	1	Forestville	2	Well	Pressure System	--	--	--
Lawndale Mutual Water Co.	61	1	Kenwood	10	SCWA	25,000	--	95	--
Lichau Hylands Mutual Water Co.	62	1	Lichau Road	30	Well	30,000	--	114	--
Loch Haven Mutual Water Co.	63	1	Porter Creek Road	8	2 Wells	10,000	--	38	--
Lower Magic Mountain Water Co.	64	3	Cazadero	20	Well				
Madrone Mutual Water Co.	65	1	Cotati	23	Well	35,000	--	136	--
Magic Mountain Water System	66	2	Cazadero	115	Well	30,000	--	114	--
Marine Cooks and Stewards School	129	3	Porter Creek Road	40	Wells	---	--	--	--
Mark West Acre Mutual Water Co.	67	1	Mark West Acres	19	Well				
McFarren Water Co.	68	3	Kenwood	18	Well	Pressure System	--	--	--



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

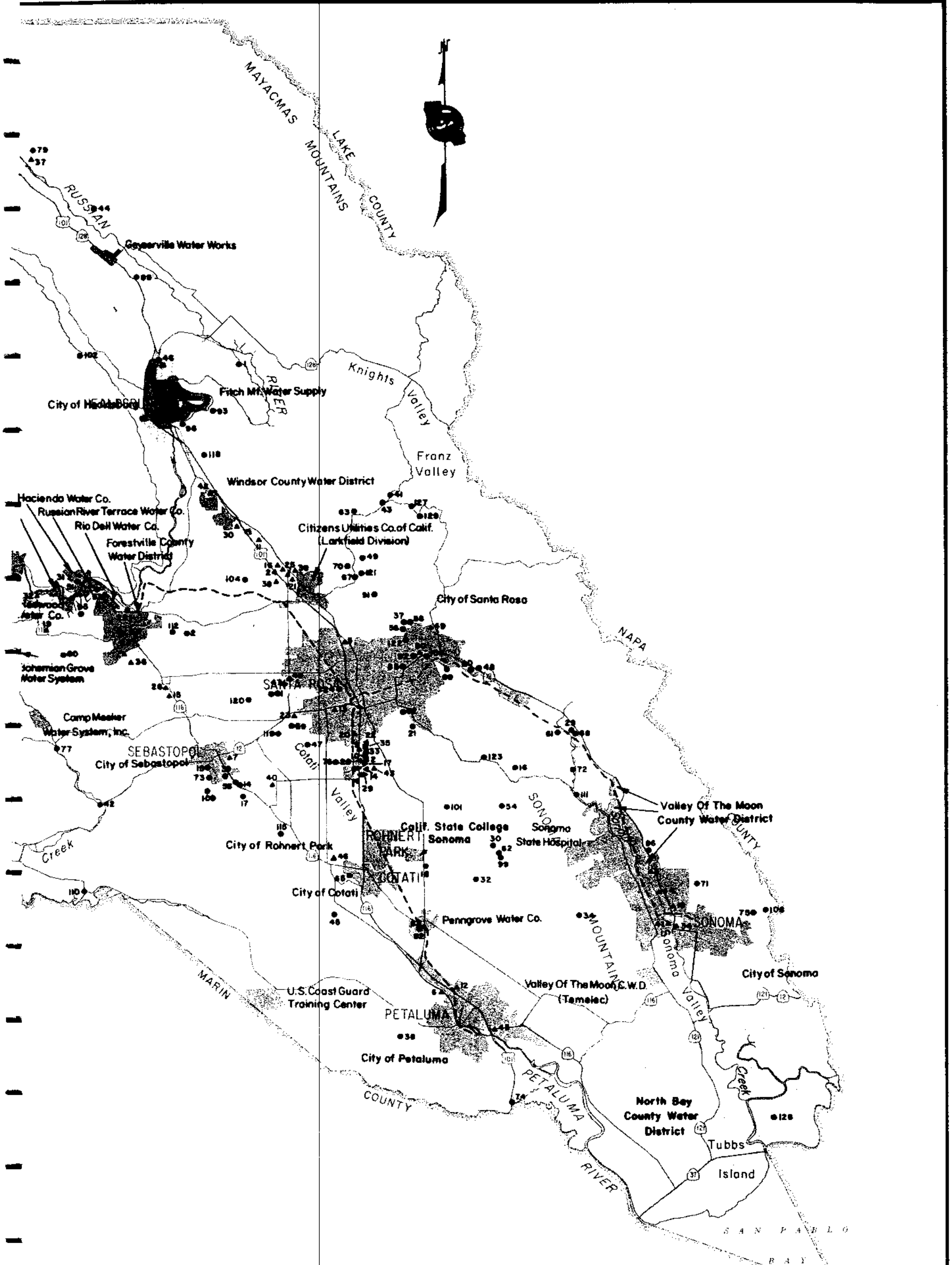
SONOMA COUNTY
GROUND WATER RESOURCES INVESTIGATION

WATER SERVICE AREAS

1975

SCALE OF MILES

FIGURE 8



BASE MAP BY SONOMA COUNTY PLANNING DEPARTMENT

Table 5

MOBILE HOME PARK WATER SYSTEMS

Name	Index No.[1]	Location	Service Connections	Source of Water	Storage Capacity (gallons)	Storage Capacity (cubic meters)
Western Mobile Home Park	1	Santa Rosa	67	2 Wells	15,000	56.8
El Crystal Trailer Park	2	Santa Rosa	56	2 Wells	Pressure System	
Hooker Oak Trailer Court	3	Sonoma	28	Well	Pressure System	
Mt. Taylor Trailer Park	4	Santa Rosa	19	Well	Pressure System	
Journey's End	5	Santa Rosa	100	4 Wells	25,000	94.5
One Mile Inn	6	Petaluma	5	Well	Pressure System	
Shady Rest Trailer Park	7	Sebastopol	86	Well	--	--
Penngrove Trailer Park	8	Petaluma	31	Penngrove Mutual Water Company		
Sunset Trailer Park	9	Santa Rosa	43	Well	Pressure System	
North Star Trailer Park	10	Santa Rosa	76	Well	Pressure System	
Royal Mobile Manor	11	Santa Rosa	79	2 Wells	--	--
Capri Mobile Villa	12	Petaluma	69	2 Wells	10,000	37.9
Roseland Mobile Home Park	13	Santa Rosa	68	Well	Pressure System	
The Trailer Corral	14	Santa Rosa	83	Well	1,000	3.8
Pine Hill Terrace Mobile Home Park	15	Sebastopol	20	Well	2,000	7.6
Mobile Home Estates	16	Santa Rosa	139	2 Wells	Pressure System	
Plaza Mobile Home Park	17	Santa Rosa	50	2 Wells	Pressure System	
Acacia Grove Motel & Trailer Court	18	Sonoma	70	Well	1,000	3.8
Pocket Canyon Cabins	19	Forestville	7	Well	Pressure System	
Wayside Gardens Mobile Home Park	20	Santa Rosa	49	2 Wells	15,000	56.8
Redwood Village Mobile Trailer Court	21	Santa Rosa	66	2 Wells	Pressure System	
Lamplighter Mobile Home Park	22	Santa Rosa	109	Well	12,000	45.4
Melody Inn Trailer Park	23	Santa Rosa	8	Well	Pressure System	
Colonial Park	24	Santa Rosa	190	Well	10,000	37.9
Ranchito Mobile Home Estates	25	Santa Rosa	32	Well	Pressure System	
Blue Spruce Mobile Home Lodge	26	Sebastopol	47	2 Wells	4,000	15.1
Timber Cove Boat Landing	27	Jenner	4	Well	Pressure System	
Lucas Park	28	Santa Rosa	14	Well	500	1.9
Lancelot Mobile Home Park	29	Santa Rosa	27	Well	--	--
Windsor Mobile Country Club	30	Windsor	200	2 Wells	23,000	87.1
School House Canyon Camp Ground	31	Guerneville	25	--	--	--
Odd Fellows Recreation Club	32	Guerneville	44	--	--	--
El Portal Mobile Estates	33	Santa Rosa	122	2 Wells	20,000	75.7
Moonlight View Mobile Home Park	34	Sonoma	7	City of Sonoma	--	--
Martini's Mobile Estates	35	Santa Rosa	107	Well	Pressure System	--
Marsh Acres	36	Sebastopol	3	--	--	--
Cloverdale KOA Campground	37	Cloverdale	98	2 Wells	--	--
Stonegate Mobile Home Park	38	Santa Rosa	60	2 Wells	Pressure System	--
Ramsey's Park	39		8	Well	Pressure System	--
One Oak Mobile Home Park	40	Sebastopol	6	--	--	--
Rancho de Sonoma	41	Sonoma	99	Artesian Well	Pressure System	--
Evergreen Mobile Park	42	Windsor	24	2 Wells	Pressure System	--
Santa Rosa Mobile Manor	43	Santa Rosa	50	--	--	--
Rancho Vista Mobile Home Park	44	Fetters Hot Springs	123	City of Sonoma	--	--
Little Woods Mobile Home Park	45	Petaluma		Wells	--	--
Gilmore Park	46	Cotati		--	--	--
Sequoia Gardens	47	Santa Rosa	151 - 191	Well	--	--
The Country	48	Santa Rosa		Well	--	--
Rancho Cabeza Mobile Home Park	49	Santa Rosa		Well	--	--
Rincon Valley Mobile Home Estates	50	Santa Rosa		Well	--	--

1/ Location shown on Figure 5.

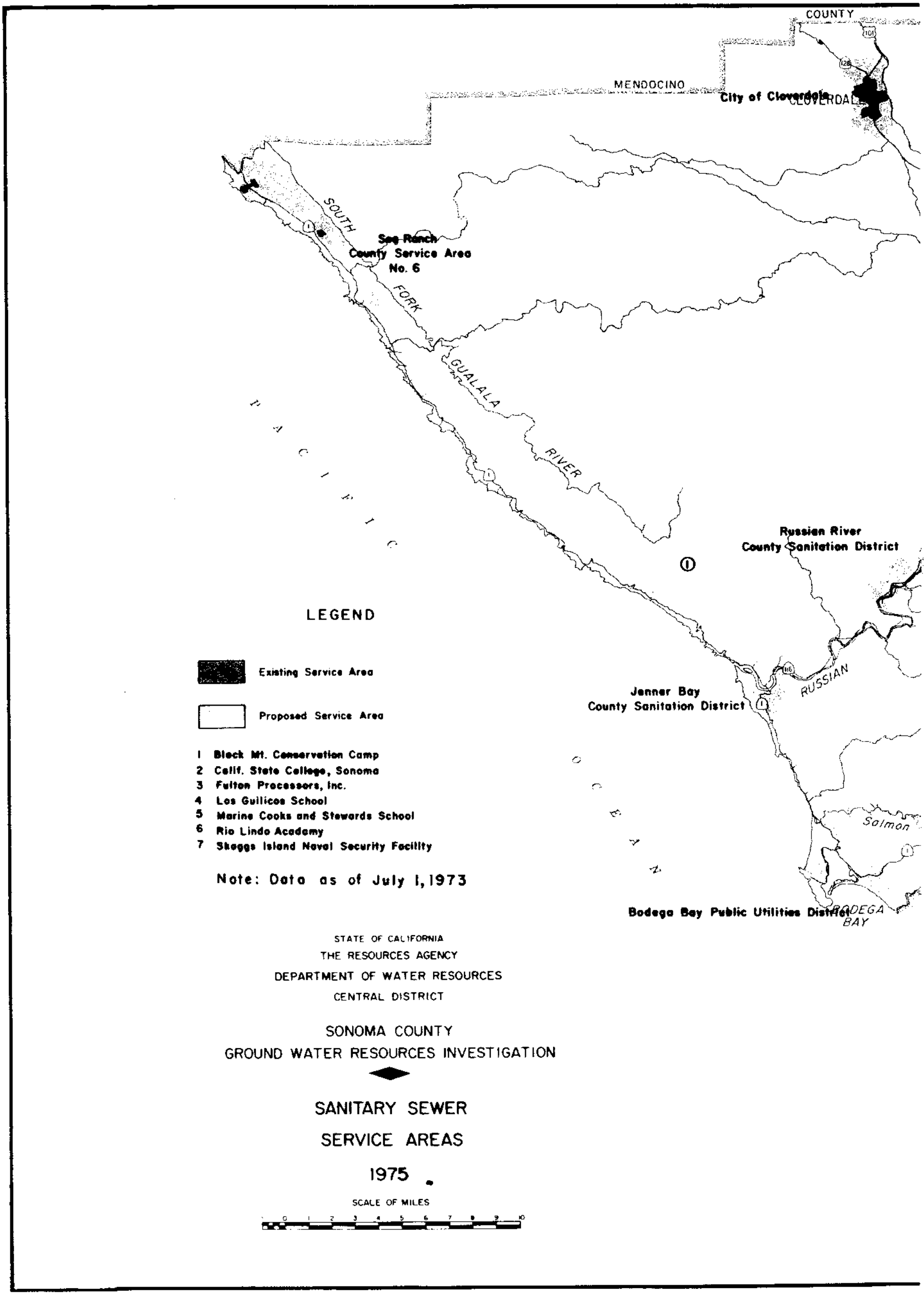
CHAPTER IV. SANITARY WASTE DISPOSAL SYSTEMS

Sonoma County, being a combination of urban and rural development, contains both municipal sewage treatment systems and homes served by individual septic tanks. The municipal systems range from those such as the Windsor County Water District, which has 2,320 service connections and a treatment plant of 0.75 million gallons per day (2,835 cubic meters per day) capacity, to the City of Santa Rosa, which has 17,500 service connections and three treatment plants with a total capacity of 9.67 MGD (36,600 m^3/d). Table 6 presents data on all of the public and private sanitary sewer systems in the county; Figure 9 shows the locations of these systems.

It long has been suspected that much of rural Sonoma County (that part of the county not served by sewer systems) is unsuitable for the construction and operation of septic tank and leach field systems. Soils data developed by Miller (1972) support this view. One of the principal aims of the current investigation is to use these soils data to identify rural areas where septic tank problems exist, and where such systems should be prohibited.

As part of the data developed regarding septic tank practice in Sonoma County, reports documenting 14 septic tank failure areas were obtained from the Sonoma County Public Health Service. Table 7 presents data on the documented septic tank failures; the locations of the failure areas are shown on Figure 10.

To augment the failure data, surface water samples were collected at 33 locations throughout the county and were analyzed for total coliform by the County Public Health Service. Sampling areas were selected on the basis of the probability of the surface water having become polluted by failing septic tanks, and usually two samples were taken, one upstream of the potential pollution to establish a "background" coliform count, and one downstream to identify any pollution. For example, a sample was taken on the unnamed stream just north of Bloomfield (see Figure 10); this sample showed a Most Probable Number (MPN) of coliform of 7,000 per 100 milliliters (ml). A sample taken on the same stream just south of Bloomfield showed an MPN of 24,000, indicating a probability of septic tank failures in the Bloomfield area. Although a certainty of septic tank failures could not be determined based solely on the presence of total coliform, it is suspected that samples which showed an MPN in excess of 1,000 indicated some degree of failure. The locations of the 33 sampling stations and the MPN of total coliform at each sampling station are shown on Figure 10.



COUNTY
MENDOCINO
City of Cloverdale
CLOVERDALE
Sea Ranch
County Service Area
No. 6
SOUTH FORK GUALALA RIVER
PACIFIC OCEAN
Russian River
County Sanitation District
RUSSIAN
Jenner Bay
County Sanitation District
Salmon
Bodega Bay Public Utilities District
BODEGA BAY
LEGEND
Existing Service Area
Proposed Service Area
1 Black Mt. Conservation Camp
2 Calif. State College, Sonoma
3 Fulton Processors, Inc.
4 Los Guilicos School
5 Marine Cooks and Stewards School
6 Rio Lindo Academy
7 Skaggs Island Naval Security Facility
Note: Data as of July 1, 1973
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT
SONOMA COUNTY
GROUND WATER RESOURCES INVESTIGATION
SANITARY SEWER
SERVICE AREAS
1975
SCALE OF MILES
0 1 2 3 4 5 6 7 8 9 10

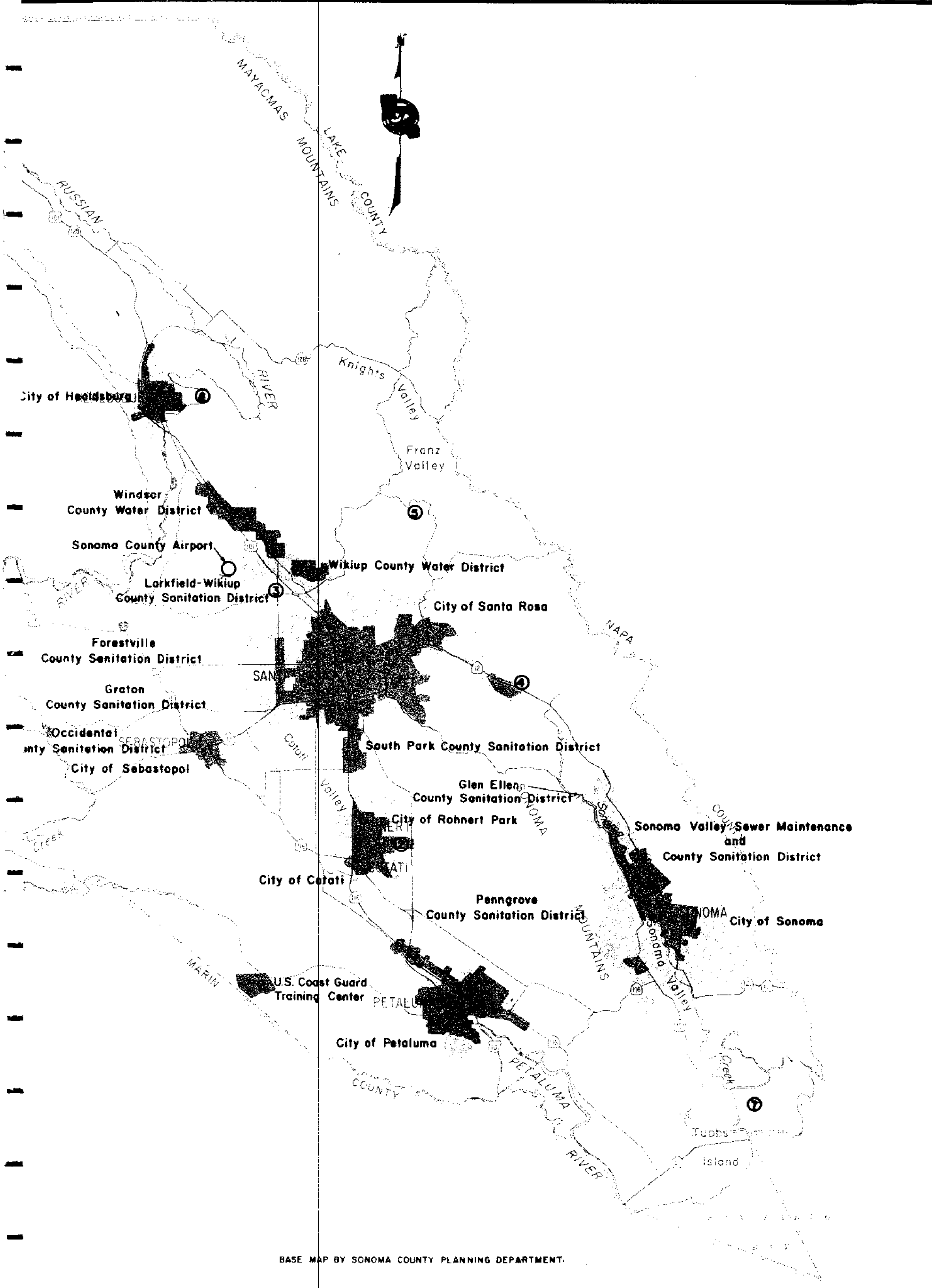

MAYACMAS MOUNTAINS
LAKE COUNTY
RUSSIAN RIVER
City of Healdsburg
Knight's Valley
Franz Valley
Windsor County Water District
Sonoma County Airport
Wikiup County Water District
Larkfield-Wikiup County Sanitation District
City of Santa Rosa
NAPA
Forestville County Sanitation District
Graton County Sanitation District
Occidental County Sanitation District
City of Sebastopol
Cotati Valley
South Park County Sanitation District
Glen Ellen County Sanitation District
SONOMA
City of Rohnert Park
Sonoma Valley Sewer Maintenance and County Sanitation District
City of Cotati
Penngrove County Sanitation District
MOUNTAINS
City of Sonoma
Sonoma Valley
MARIN
U.S. Coast Guard Training Center
City of Petaluma
PETALUMA RIVER
COUNTY
Creek
Tubbs Island
BASE MAP BY SONOMA COUNTY PLANNING DEPARTMENT.

Table 6

SANITARY SEWER SYSTEMS

Name	Area Served	Type	Number of Service Connections	Treatment Plant Capacity: Million Gallons per Day	Treatment Plant Capacity: Cubic Meters per Day
Black Mountain Conservation Camp	Camp	Private	6	0.002 1/	7.6
California State College, Sonoma	College	Private	---	2/	---
City of Cloverdale	Cloverdale	Municipal	1,389	2.0	7,570
City of Cotati	Cotati	Municipal	430	2/	---
Forestville County Sanitation Dist.	Forestville	County District	50	0.082	310
Fulton Processors, Inc.	Fulton Packing Plant	Private	1	0.2 3/	757
City of Healdsburg	Healdsburg	Municipal	2,090	2.0	7,570
Los Guilicos School	School	Private	40	0.1	379
Marine Cooks and Stewards School	School	Private	40	0.2	757
Occidental County Sanitation Dist.	Occidental	County District	50	0.05	189
City of Petaluma	Petaluma	Municipal	9,500	3.0	11,355
Rio Linda Academy	School	Private	40	1.5 3/	5,678
City of Rohnert Park	Rohnert Park	Municipal	3,200	1.5	5,678
City of Santa Rosa	Santa Rosa	Municipal	17,500	9.67	36,600
Sea Ranch County Service Area #6	Sea Ranch	County District	234	0.034	129
City of Sebastopol	Sebastopol	Municipal	1,520	0.7	2,650
Skaggs Island Naval Facility	Naval Station	Federal	91	0.144	544
Sonoma County Airport	Airport	Municipal	15	0.08	302
Sonoma Valley County Sanitation and Sewer Maintenance District	Sonoma, El Verano, Boyes Springs, Agua Caliente, Temelec	County District	5,650	1.5	5,678
South Park County Sanitation Dist.	South Santa Rosa	County District	2,860	4/	
U. S. Coast Guard Training Center	Two Rock Ranch	Federal	150	0.19	121
Wikiup County Water District	Larkfield-Wikiup	County District	130	0.1	384
Windsor County Water District	Windsor	County District	2,320	0.75	2,835

1/ Septic system.
2/ No treatment plant; delivers to Rohnert Park system.
3/ Oxidation ponds.
4/ No treatment plant; delivers to Santa Rosa system.

Table 7

DATA ON SEPTIC SYSTEM FAILURES[a/]

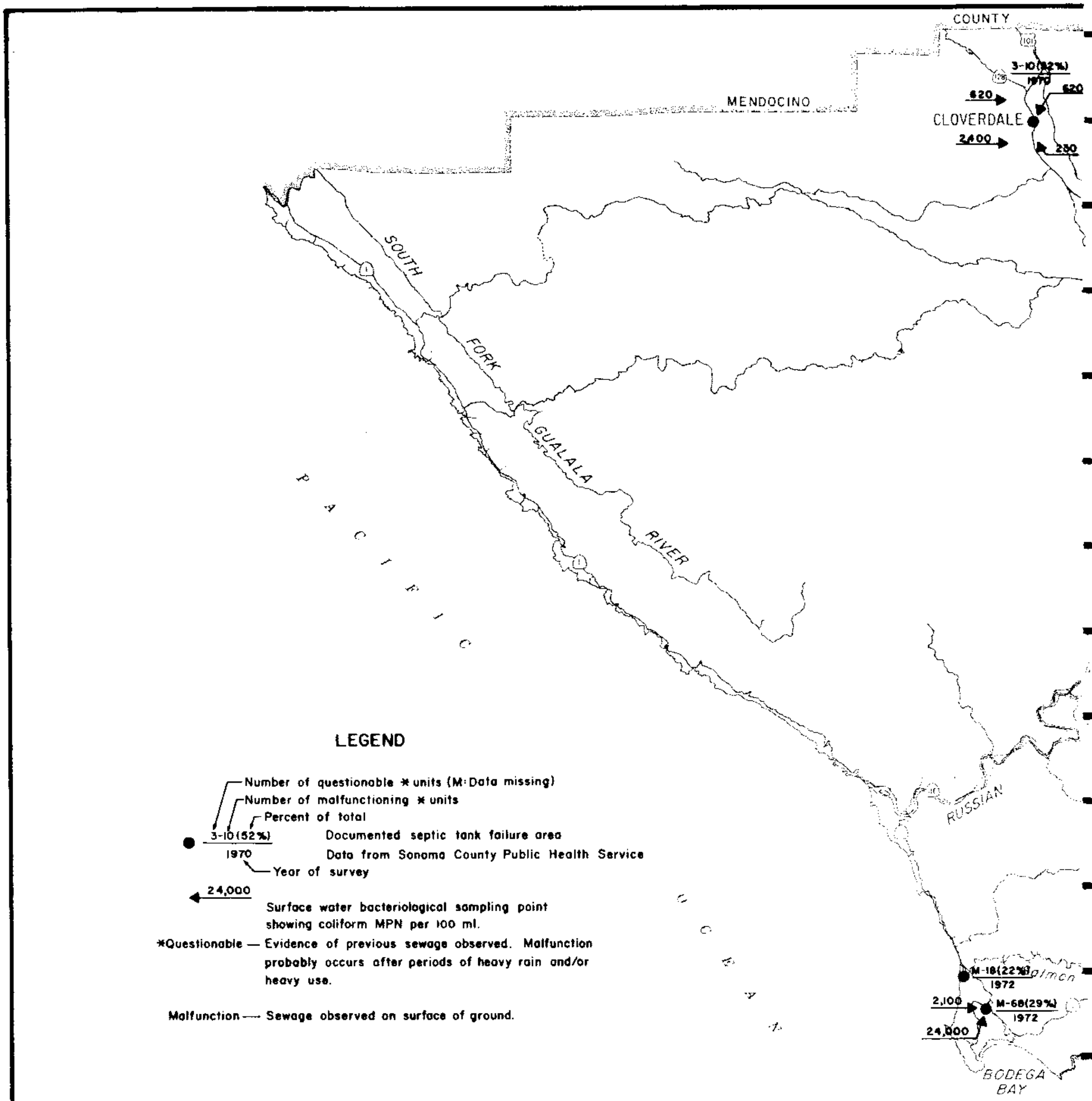
Area	Location	Date of Failure	Number of Septic Systems Inspected	Satisfactory No.	Satisfactory %	Questionable[b/] No.	Questionable[b/] %	Malfunction[c/] No.	Malfunction[c/] %	Remarks
Middle Rincon Road Assessment Dist.	Rincon Valley	4-1971	61	26	42.5	6	10.0	29	47.5	
Edgewood Farms	Rincon Valley	2-1966	110	79	72	16	15	15	14	
Bodega Bay	Bodega Bay	11-1972	238	170	71.5	-	-	68	28.5	Effluent flows into Bodega Bay.
Salmon Creek	Salmon Creek	11-1972	81	63	77.8	-	-	18	22.2	Effluent present in roadside ditches.
Hollard Heights	Bennett Valley	1-1972	101	51	50.5	11	10.9	39	38.6	
Lake Street	Cloverdale	4-1970	25	12	48	3	12	10	40	Probably 100% failure rate during winter.
Windsor	Windsor	1961	388	202	52.1	-	-	186	47.9	
South Edison St.	Graton	2-1965	31	6	16.1	-	-	26	83.9	71% of wells sampled showed presence of coliform.
Graton	Graton	2-1972	148	45	30.4	-	-	103	69.6	50% of wells sampled showed presence of coliform. 11 surface water samples showed presence of coliform.
Glen Ellen	Glen Ellen	4-1967	50	34	68	-	-	16	32	Effluent flows into Sonoma Creek.
Glen Ellen	Glen Ellen	10-1972	260	161	61.7	43	16.7	56	21.6	
Fircrest Avenue	Sebastopol	1969	21	19	90.5	-	-	2	9.5	
Belmont Terrace	Sebastopol	2-1971	44	23	53	3	6	18	40	
Rinconada Avenue	Rincon Valley	1966	57	33	62	2	1	22	37	
Montecito Avenue	Rincon Valley	1971	229	188	82	15	7	26	11	
Penngrove	Penngrove	1971	98	10	11	-	-	87	89	

a/ Data from Sonoma County Health Service.
b/ Questionable: Evidence of previous sewage observed. Malfunction probably occurs after periods of heavy rain and/or heavy use.
c/ Malfunction: Sewage observed on surface of ground.

Septic Tank Acceptability

To determine whether septic tanks can be efficiently constructed, operated, and maintained in a given area, a knowledge of the soil and topographic characteristics of that area is essential. Physical factors, such as soil type, soil depth, ground slope, and presence of ground water, have bearing on the siting of septic tanks and leach fields. Directional factors, such as distance to property lines, cuts, fills, water wells, and bodies of water also are important.

The physical factors are, perhaps, the most critical in the determination as to whether a septic tank system can be placed on a particular parcel of property. The soils in Sonoma County range from alluvial valley and basin soils to residual mountain soils; each has its own unique physical characteristics. One criterion for the division of soils into septic tank acceptability groups is that of permeability, which is the measure of the ability of the soil to absorb and transmit fluids. Obviously, if a soil is of such low permeability that it cannot absorb fluids,



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

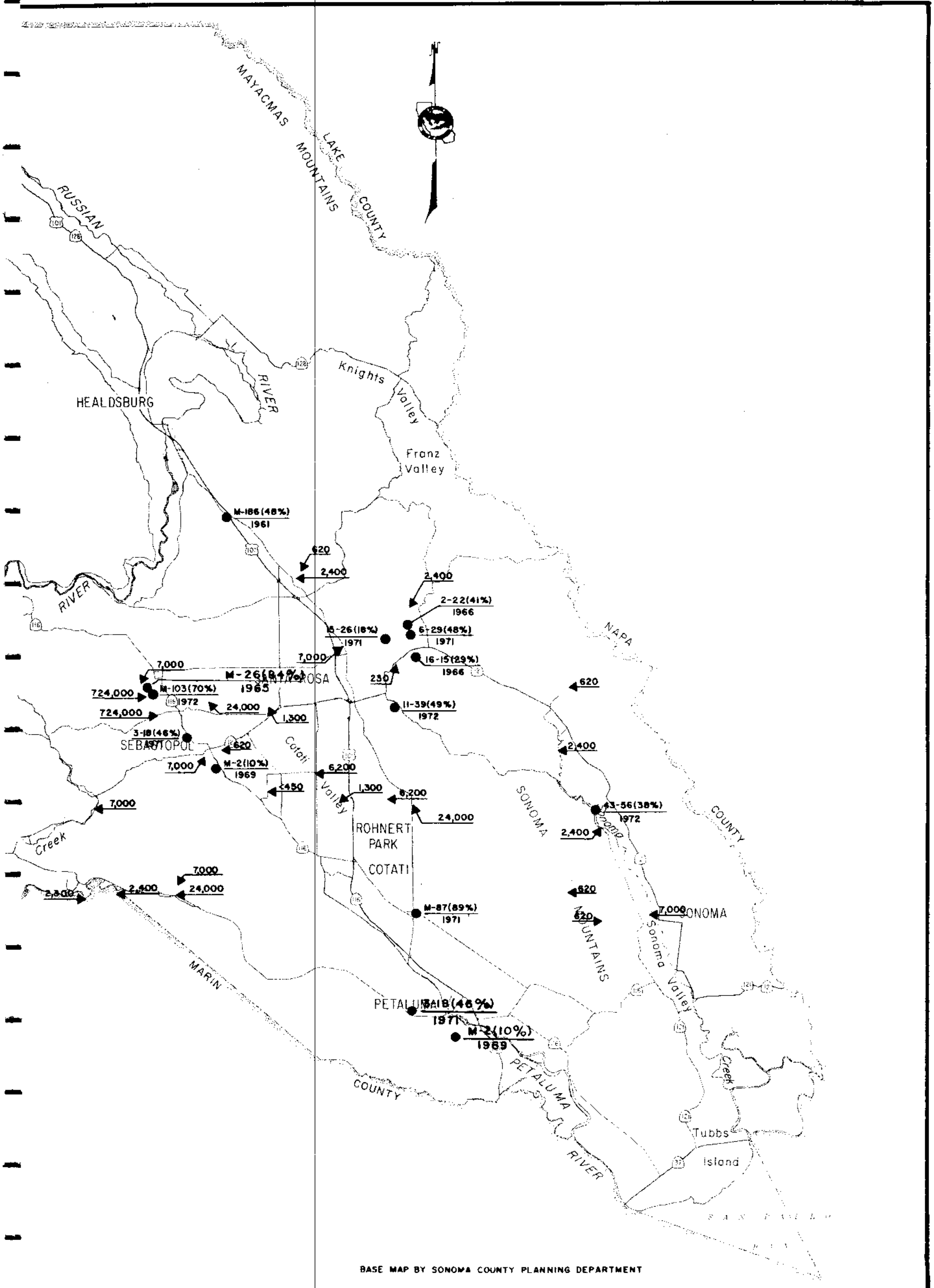
SONOMA COUNTY
GROUND WATER RESOURCES INVESTIGATION

SEPTIC TANK FAILURES
AND
BACTERIOLOGICAL SAMPLING POINTS

1975

SCALE OF MILES

0 1 2 3 4 5 6 7 8 9 10


MAYACMAS MOUNTAINS
LAKE COUNTY
RUSSIAN RIVER
HEALDSBURG
Knights Valley
Franz Valley
SANTA ROSA
SEBASTOPOL
Cotati Valley
ROHNERT PARK
COTATI
SONOMA MOUNTAINS
NAPA COUNTY
SONOMA
Sonoma Valley
PETALUMA
PETALUMA RIVER
MARIN COUNTY
Tubbs Island
Creek
BASE MAP BY SONOMA COUNTY PLANNING DEPARTMENT

it is totally unsuitable for the placement of a septic tank system. Conversely, soils with a rate of percolation of up to 60 minutes per inch (mpi) or 25 minutes per centimeter (m/cm) have adequate permeability to accept and transmit effluent.

Because of the critical nature of the percolation rates of soils, it is important that percolation tests be performed correctly. Tests should be carried out during the most adverse time of the year (during a time when soils are wet and standing water is at its highest level).

Septic Tank Percolation Tests

A septic tank percolation test measures the rate of drop of the level of water in a test hole excavated into the area of a proposed leach field. Thus, the rate of drop of the water level is related to the percolative capacity of the soil in the proposed leach field area. Standards of percolation test hole construction and testing have been established by the Sonoma County Public Health Service. These standards are presented in Appendix E to this bulletin.

Septic Tank Siting

The depth of soil cover is important for a leach field system because there must be sufficient soil mantle underlying the leach field area to filter and purify effluent. A great number of the bacteria contained in sewage effluent are effectively removed by downward percolation through several feet of soil. The removal process involves mechanical and biological straining (a result of soil clogging) and/or destruction by environmental changes (soil defense mechanisms). Soil clogging is the increase in physical resistance to flow and generally occurs within the first six inches (15 cm) of soil near the leach line. Soil defense mechanisms occur at a greater distance and involve the destruction of harmful bacteria by: (1) the latter's inability to adjust to changes in temperature; (2) oxygenation and nitrification; and (3) destruction by naturally-occurring soil bacteria. Thus, water of a bacterial quality suitable for drinking purposes can be obtained after passing coliform-laden effluent through a thickness of soil which is dependent on soil structure and conditions. Furthermore, coliform can be effectively removed from effluent even if the soil is a fairly coarse-grained dune sand. Experiments illustrating this latter fact were conducted by the University of California, Sanitary Research Engineering Laboratory (1955) who reported that coliform was reduced from 70,000 to 700 after percolation through 12 feet (4 m) of dune sand.

In view of the above depth requirements, soils which are less than five feet (1.5 m) deep, this is, two feet (0.6 m) deep below the invert of a 3-foot (0.9 m) deep leach line, are unsuitable for the placement of a septic tank and leach field. In contrast, as the soil gets progressively deeper, it becomes more acceptable; the most ideal depth of soil for septic tanks is that in excess of 22 feet (6.5 m).

The ground slope is extremely important with regard to septic tank siting. If slopes are greater than 30 percent, there is a possibility that untreated effluent may move laterally from the leach line and emerge on to the ground surface. The effluent then could move downslope onto adjacent property, pond at the base of a cut slope, or run into a body of water. Furthermore, slopes steeper than 30 percent could be subject to sheet erosion, which might wash out a leach line. Hence, if the horizontal distance from the bottom of the leach line to the ground surface is 10 feet (3 m) or less, the land is too steep for a septic system to operate efficiently.

The depth to ground water is a vital factor in siting septic tanks because without adequate filtration in the zone of aeration (above the water table), septic effluent could enter the ground water body and spread down gradient. Romero (1970) reported that fecal <u>Bacillus coli</u> and other pollutants travel as a thin sheet on the surface of the zone of saturation (the water table). This sheet can spread down gradient, and <u>Bacillus coli</u> has been reported as far as 80 feet (24 m) from the source of pollution. Thus, in order to provide a sufficient depth for filtration, the minimum seasonal depth to water must be not less than 5 feet (1.5 m) below the leach line invert, or 8 feet (2.4 m) below the ground surface.

<u>Soils Classifications for Septic Tanks</u>

Using soils data developed by Miller (1972), all of the soils in Sonoma County were classified according to their respective permeability, slope, depth to rock, and minimum depth to seasonal high water. The classification resulted in three basic septic tank acceptability groups being identified; one of the groups was further subdivided into three subgroups. Each septic tank acceptability group and subgroup is briefly described below. Table 8 presents the relationship of each soil series with its septic tank acceptability group; Table 9 shows the total area for each group and subgroup. Plate 2 shows the general areal extent of each septic tank acceptability group. For specific septic tank siting, the soils maps at a scale of 1:20,000 in the report by Miller (1972) are recommended for use in connection with data on Table 8 in this bulletin.

Table 8 (Continued)

RELATION OF SOIL SERIES TO SEPTIC TANK ACCEPTABILITY[1/]

Soil Series[2/]	Symbol[2/]	Percolation Rate				Slope		Depth to Water		Depth to Rock or Impervious Stratum			Classification[3/]
		<5 mpi <2m/cm	5-60 mpi 2-25 m/cm	60-120 mpi 25-50 m/cm	>120 mpi >50 m/cm	<30%	>30%	<8 ft <2.4m	>8 ft >2.4m	<2 ft <0.6m	2-7 ft 0.6-2m	>7 ft >2m	
Sobrante	ShE		x	x		x			x		x		PR
Sobrante	ShF, ShG		x	x			x		x		x		U
Spreckles	SkC, SkD, SkE, SkE2				x	x			x		x		U
Spreckles	SkF				x		x		x		x		U
Steinbeck	SnC, SnD, SnD2, SnE, SnE2		x	x		x			x		x		PR
Steinbeck	SnF, SnF2		x	x			x		x		x		U
Stonyford	SoF, SoG, SrG		x	x			x		x	x			U
Supan	SsG			x	x		x		x		x		U
Suther	StE, StE2				x	x			x		x		U
Suther	StF, SuF, SuG				x		x		x		x		U
Tidal Marsh	TmA				x	x		x				x	U
Toomes	ToE		x	x		x			x	x			U
Toomes	ToG		x	x			x		x	x			U
Tuscan	TuC, TuE				x	x			x	x			U
Wright	WgC, WhA, WmB, WoA				x	x		x				x	U
Yolo	YlA, YnA, YrB, YsA, YtA		x	x		x			x			x	P
Yolo	YmB, YoB		x	x		x		x[4/]	x			x	U
Yorkville	YuE				x	x			x		x		U
Yorkville	YuF, YvF, YwF, YwG				x		x		x		x		U
Zamora	ZaA, ZaB			x	x	x			x			x	U

1/ Interpretation of soils data from Miller, V. C. (1972), "Soil Survey of Sonoma County, California".
2/ See Miller, V. C. (1972).
3/ Soil classification:

A - Acceptable soils.
P - Potentially acceptable soils - Permeability constraints may be present.
R - Potentially acceptable soils - Soil depth constraints may be present.
PR - Potentially acceptable soils - Permeability and soil depth constraints may be present.
U - Unacceptable soils.

4/ Subject to flooding.

Table 9

SEPTIC TANK ACCEPTABILITY GROUPS

Group and Subgroup	Area (Acres)	Area (Hectares)	Percent of Total Area of County
Acceptable soils	6,255	2,531	0.61
Potentially acceptable soils	67,118	27,162	6.64
Permeability constraints	16,600	6,718	1.64
Soil depth constraints	1,818	736	0.18
Permeability and soil depth constraints	48,700	19,708	4.82
Unacceptable soils	937,817	379,535	92.75
Total	1,011,190	409,228	100.00

Acceptable Soils

Some 6,255 acres (2,531 ha) of Sonoma County, or 0.61 percent of the total area of the county, are underlain by soils with generally acceptable characteristics for the placement of septic tanks and leach fields. These soils belong to the Baywood and Cortina series and have percolation rates which range from 5 to 60 mpi (2 to 25 m/cm). The remaining soils of this group belong to the Noyo series. Although these latter soils generally have a percolation rate less than 60 mpi (25 m/cm), Miller (1972) reported that this soil series has a clayey zone at a depth of from 29 to 53 inches (74 to 135 cm), which has a percolation rate ranging from 200 to 600 mpi (80 to 240 m/cm). Slope, depth to rock, and depth to water are all in the acceptable range for soils of this subgroup. Septic tanks can be placed on soils of this subgroup if on-site tests prove that percolation rates are less than 60 mpi (25 m/cm).

Potentially Acceptable Soils

Many of the valley and upland soil types of Sonoma County are potentially acceptable for leach fields. Because of a lack of detailed soils data, all of these soils have been grouped as potentially acceptable, because their characteristics range from those in the acceptable range to those that are unacceptable. Final determination of the acceptability of any soils in this group will depend on detailed on-site field analysis on a case-by-case basis. The soils of this group have been subdivided into the following three subgroups:

Permeability Constraints. The soils of this subgroup underlie 16,600 acres (6,718 ha) of valley hill lands and belong to the Felta and Yolo series. They have percolation rates which range from 5 to over 120 mpi (2 to over 50 m/cm). Slope, depth to rock, and depth to water are all in the acceptable range for soils of this subgroup. Septic tanks can be placed on soils of this subgroup when on-site tests prove that the percolation rate is less than 60 mpi (25 m/cm).

Soil Depth Constraints. Soils of this subgroup underlie 1,818 acres (736 ha) of hill lands. These soils belong to the Kneeland (sandy variant) and Sheridan series and range in depth from 2 to 7 feet (0.6 to 2.1 m). Slope, percolation rate, and depth to water are in the acceptable range. Septic tanks can be placed on soils of this subgroup where on-site tests prove that the soil depth is at least 5 feet (1.5 m).

Permeability and Soil Depth Constraints. Soils of this subgroup underlie 48,700 acres (19,708 ha) of hill lands; the soils belong to nine different series (see Table 8). These soils have percolation rates which range up to 300 mpi (125 m/cm) and depths which range from 4 to 7 feet (1.2 to 2.1 m); slope and depth to water are both in the acceptable range. Septic tanks can be placed on soils of this subgroup where on-site tests prove that the percolation rate is less than 60 mpi (25 m/cm) and the soil depth is at least 5 feet (1.5 m).

Unacceptable Soils

Of the 256 different soil units mapped by Miller (1972), 226 have characteristics which make them unacceptable for the placement of septic tank and leach field systems. The unacceptable soils underlie 937,817 acres (379,535 ha), or 92.75 percent of the total area of the county. The uncolored areas on Plate 2 show the areal extent of the unacceptable soils. These soils all have one or more of the following characteristics:

1. Percolation rates are greater than 60 mpi (25 m/cm).

2. Slope is steeper than 30 percent.

3. Depth to rock or other impermeable barrier is less than 2 feet (0.6 m) below the invert of the leach line (that point where effluent leaves the pipe and enters the soil) or 5 feet (1.5 m) below the ground surface.

4. The depth to standing water is less than 8 feet (2.4 m) below the ground surface.

5. They are subject to periodic flooding.

Certain areas of Sonoma County are underlain by sandstones of the Merced and Ohlson Ranch Formations (see Plate 1). Many such areas contain soils of the Goldridge series which have been classified as being unacceptable for placement of septic tanks because of shallow soil depth. Where this condition is the case, on-site percolation tests may show that the underlying geologic materials have adequate percolation capability for the placement of a septic tank and leach line system.

Recommended Minimum Leach Field Area

After determining that the soil on a given parcel of land has acceptable characteristics for the siting of a septic tank system and the slope of the ground surface has been determined, the minimum leach field area can be determined by using Table 10. This table was derived from data prepared by the U. S. Department of Health, Education and Welfare (1972) and the California Water Quality Control Board, Central Valley Region. The minimum area shown on the table is twice the amount required for the initial leach field as it provides space for future leach field replacement.

The minimum leach field area should not include any of the following:

1. Building setbacks required by ordinance or code;

2. Easements dedicated or reserved for surface or underground improvements unless dedicated or reserved for sewage disposal purposes;

3. Easements for access or roadway purposes;

4. Areas occupied by structures or to be occupied by proposed structures and areas within 5 feet (1.5 m) of such structures. For the purpose of single-family residential lots, on which there are no existing structures, this area shall be assumed to be 2,500 square feet (230 m^2);

Table 10

RECOMMENDED MINIMUM DISPOSAL AREAS FOR LEACH FIELDS[1/]

Slope (percent)	Percolation Rate (Minutes per Inch)	Soil Depth 5 Feet	6 Feet	7-12 Feet	13-17 Feet	18-22 Feet	Over 22 Feet
		(Square-Feet)					
0-10	<10	21,000	16,000	11,000	6,000	6,000	6,000
	10-20	23,000	18,000	13,000	8,000	8,000	8,000
	20-40	25,000	20,000	15,000	10,000	10,000	10,000
	40-60	27,000	22,000	17,000	12,000	12,000	12,000
11-20	<10	29,000	24,000	19,000	14,000	11,000	9,000
	10-20	31,000	26,000	21,000	16,000	13,000	11,000
	20-40	33,000	28,000	23,000	18,000	15,000	13,000
	40-60	35,000	30,000	25,000	20,000	17,000	15,000
21-30	<10	36,000	31,000	26,000	21,000	19,000	16,000
	10-20	38,000	33,000	28,000	23,000	21,000	18,000
	20-40	40,000	35,000	30,000	25,000	23,000	20,000
	40-60	1 Acre	37,000	32,000	27,000	25,000	22,000

Slope (percent)	Percolation Rate (Minutes per Centimeter)	Soil Depth 1.5 Meters	1.8 Meters	2.0-3.5 Meters	3.5-5.0 Meters	5.0-6.5 Meters	Over 6.5 Meters
		(Square-Meters)					
0-10	<4	2,000	1,500	1,000	550	550	550
	4-8	2,200	1,700	1,200	750	750	750
	8-16	2,400	1,900	1,400	900	900	900
	16-24	2,600	2,100	1,600	1,100	1,100	1,100
11-20	<4	3,300	2,500	1,800	1,300	1,000	800
	4-8	3,500	2,700	2,000	1,500	1,200	1,000
	8-16	3,700	2,900	2,200	1,700	1,400	1,200
	16-24	3,900	3,100	2,400	1,900	1,600	1,400
21-30	<4	4,400	3,400	2,400	2,000	1,800	1,500
	4-8	4,600	3,600	2,600	2,200	2,000	1,700
	8-16	4,800	3,800	2,800	2,400	2,200	1,900
	16-24	5,000	4,000	3,000	2,500	2,400	2,100

1/ Data from California Water Quality Control Board, Central Valley Region

5. Areas within 5 feet (1.5 m) of property lines;

6. Areas which fall within the geographical constraints shown on Table 11; and

7. Areas which are paved or proposed to be paved.

Geographical Constraints

After the minimum disposal area has been determined from Table 10, the exact location of the leach field can be determined only after geographical constraints have been considered. These constraints, which are shown on Table 11, provide distances which allow sufficient travel time for the purification of septic effluent.

Romero (1970) states that bacteria and viruses have been known to survive for up to five years in soils under ideal conditions; he also states that the travel distance of organisms in non-saturated systems appears to be on the order of about 10 feet (3 m). However, bacteria and/or virus infested pollutants might travel much farther if nutrient-laden waters are intercepted during the course of percolation.

Leach Field Design and Operation

The leach field is the part of the septic disposal system that is most prone to failure. Failure is indicated by a decline in the ability of the system to accept and dispose of effluent at the design rate, leading to eventual breakthrough of liquid to the ground surface. Failure may eventually occur in a poorly-designed system even though soils and geographic location appeared to be favorable at the time of construction. Failure may be due, in large part, to the assumption that data on the short-term percolative capacity of a soil could be used to predict the long-term behavior of the leach field system. The problem leading from this assumption may be further compounded by the variability of the soils in question because data from the percolation test holes might not be characteristic of the entire percolation field soil.

According to McGauhey and Winneberger (1967), the following items are pertinent to septic tank systems:

1. A percolation test can only identify a soil that is capable of transporting water providing its infiltrative capacity (the rate at which water is absorbed by the soil) is maintained.

Table 11

GEOGRAPHIC CONSTRAINTS FOR
SITING SEPTIC TANKS AND LEACH FIELDS[a]

Feature	Septic Tanks, Minimum Horizontal Distance		Leach Field, Minimum Horizontal Distance	
	(feet)	(meters)	(feet)	(meters)
Building or Structures	5	1.5	8	2.5
Property Line	5	1.5	5	1.5
Water Well[b]	100	30	100	30
Perenially Flowing Streams[c]	100	30	100	30
Drainage Course or Ephemeral Stream[d]	50	15	50	15
Ocean, Lake, or Reservoir[e]	100	30	100	30
Large Trees	10	3	10	3
Leach Field	5	1.5	--	--
Water Pipe	5	1.5	5	1.5
Fill Areas	--	--	15	4.5
Cut Slope[f]	10	3	40	12

a/ Data from Sonoma County Public Health Service.
b/ Minimum horizontal distance in downslope direction of ground, down-gradient direction of water table, or downdip direction of geologic materials.
c/ Measured to line which defines limit of 10-year frequency flood.
d/ Measured to edge of channel.
e/ Measured to high water line.
f/ Measured distance to top of cut bank must exceed 4 times depth of cut.

2. The percolative capacity of a soil (the rate at which water will move through the soil after it has been absorbed) can be estimated only after percolation tests have been conducted at a sufficient number of locations on the leach field site.

3. Except when water is first applied, the infiltrative capacity of any soil is always less than its percolative capacity.

4. The infiltrative capacity of a soil decreases with time and is a function of soil clogging.

5. Because the infiltrative capacity of a soil is less than its percolative capacity, the most important aspect of the design and operation of a leach field is to maintain the infiltrative capacity of the soil as near as possible to its percolative capacity.

McGauhey and Winneberger have suggested that the following two criteria are very important to the design of a septic tank leach field:

1. Any soil continuously inundated will lose most of its initial infiltrative capacity. In leaching systems, this leads to failure if the system is designed on the basis of initial infiltration rates higher than the ultimate low rate.

2. Maintain the leach field system under aerobic conditions by using alternative periods of loading and resting on a regular cycle. In the absence of loading and resting cycles, anaerobic conditions will set in resulting in the rapid growth of slimes and the deposition of ferrous sulfide.

Water Wells and Septic Tanks on Rural Lots

Rural homesites usually require individual water wells and septic tank systems because the property is either beyond the service area boundaries of water purveyors and sanitary systems or it is uneconomical to connect to systems because of geography or topography. Some rural homesites are in valley or foothill areas underlain by soils which are deeper than 5 feet (1.5 m). Where the soils are shown to be otherwise acceptable for the placement of a septic tank and leach field system, a distance of 100 feet (30 m), as shown on Table 11, will be adequate separation between the leach field and any domestic water well. However, on mountain lots, a different situation frequently exists. Here, soils have only a minimum acceptable depth and the lot may be served by a "hard rock" water well. Hence, there is a possibility that some effluent might reach the soil-rock interface and then move laterally along joints, fractures, or bedding planes toward the well.

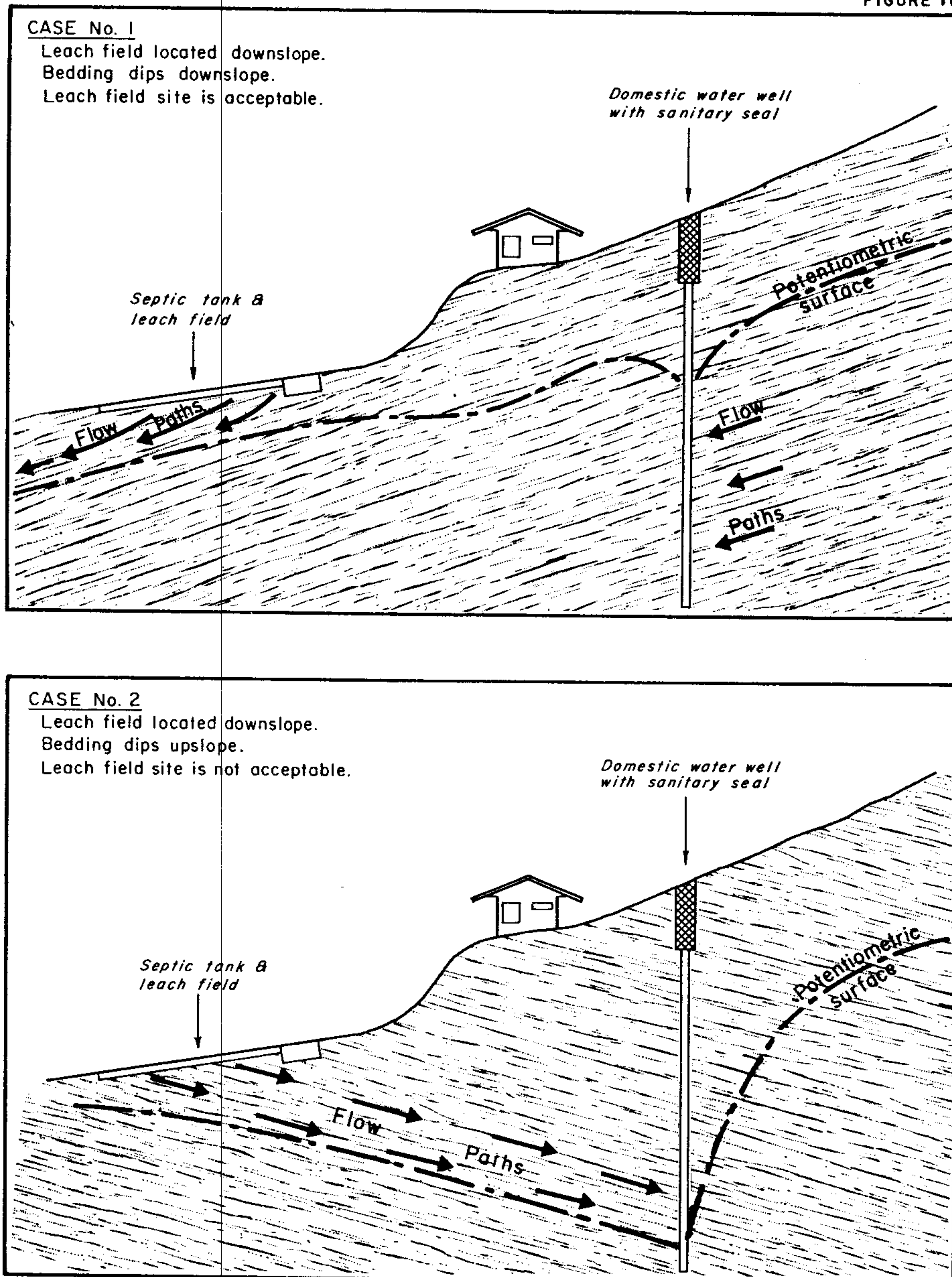
According to work done by Allen and Morrison (1973), bedding planes, joints, and fractures readily accept and convey percolating effluent. The direction and rate of movement of the effluent is largely affected by the anisotropy of these bedrock openings, and it is suspected that the effluent can move as far as 200 feet (60 m). Because the openings may contain little, if any, filling, there would be insufficient purification of the effluent, and thus, it could enter and pollute a nearby "hard rock" water well. For example, on rural lots, the septic tank and leach field normally is located downhill from the water well, as shown on Figure 11. In Case No. 1, the rock strata dip downhill and effluent from the leach field, if it entered the rock mass, would flow to the left and cause no threat of pollution. In contrast, Case No. 2 depicts a topographically identical situation to Case No. 1. In this latter case, however, the rock strata dip from the area of the leach field toward the water well. Because of this latter situation, effluent from the leach field might flow down-gradient, to the right, and enter the water well at some depth below the bottom of the sanitary seal.

Waltz (1972) has reported on a number of studies of mountainous areas in Colorado involving septic tanks and "hard rock" water wells. Water samples from some of the wells contained *Escherichia coli*, indicating pollution from nearby septic tanks. The studies showed that there are at least 10 variables involved in the hydraulic system between a septic tank and a "hard rock" water well. The two most important variables are:

1. The horizontal angle between the average direction of dip of bedding, fractures, and joints and the line between the leach field and the water well.

2. The horizontal angle between the direction of ground slope at the leach field and the line between the leach field and the water well.

Waltz showed that if either of the two variables was less than 90°, then there was a possibility that effluent could move laterally from the leach line to the water well. Furthermore, the studies showed that the probability of pollution increased at a significant rate as the angular values of the two variables decreased.



DIAGRAMMATIC SITING OF LEACH FIELD AND WATER WELL

CHAPTER V. GROUND WATER RESOURCES

Sonoma County may be divided into three ground water resource regions. One is the valley areas comprising the seven ground water basins found in the county. A ground water basin is an area that is underlain by water-bearing materials and is the location of the major ground water development. Ground water usually is available in predictable quantities nearly everywhere within the limits of a ground water basin. The seven ground water basins in Sonoma County have an aggregate area of 268.7 square miles (695.9 square kilometers) and comprise 17 percent of the total area of the county. The ground water basins, with their respective subbasins, their areal extents, and the number of identified water wells in each subbasin, are listed on Table 12; the locations of the ground water basins and subbasins are shown on Figure 12.

The contiguous and detached ground water areas shown on Figure 12 comprise an important ground water terrain in Sonoma County. Underlying 428.3 square miles (1,109.3 km^3), or 27.1 percent of the total area of the county, this terrain is the site of many hundreds of water wells. Geologic materials of the contiguous terrain range from sandstones of the Merced Formation, which may yield large quantities of ground water to wells, to rocks of the Sonoma volcanics, which in certain areas yield only minimal supplies of water.

Detached ground water areas include the following: the Annapolis area, which is underlain by the Ohlson Ranch Formation; Sea Ranch, which is underlain by marine terraces; the small alluvial valleys at the mouths of Gualala River, Russian Gulch, Scotty Creek, and Estero Americano; and the sand dune and terrace area surrounding Bodega Bay. In all of the detached ground water areas, well yields are variable because deposits usually are thin and may be nearly completely drained.

Much of the remainder of the county is underlain by nonwater-bearing rock which is not considered to be a predictable source of ground water. Occasional wells may be developed in these rock areas yielding supplies of ground water adequate for most domestic or stock supplies.

Ground Water Movement and Depth

Ground water moves generally toward the central and lower portions of the various ground water basins. Although data are insufficient to develop a ground water contour map depicting the present conditions, none of the existing data suggest a general direction of movement of ground water counter to that shown by Cardwell (1958) and Kunkel and Upson (1960).

One of the difficulties in developing a usable map showing contours on the elevation of the potentiometric surface is the true representation of the many water levels present in wells. Wells of differing depths may have widely different water levels even though they are located only a short distance apart. For example, wells in the depth range of less than 100 feet (30 meters) in Section 17, Township 5 North, Range 5 West, have an average depth to water of 46 feet (14 meters). Wells in the same section in the depth range of from 200 to 300 feet (60 to 90 meters) have an average depth to water of only 7 feet (2.1 meters). In contrast, wells located in Section 10, Township 5 North, Range 6 West, in the depth range of from 100 to 200 feet (30 to 60 meters), have an average depth to water of 7 feet (2.1 meters), while wells in the same section in the depth range of from 300 to 400 feet (90 to 120 meters) have an average depth to water of 130 feet (40 meters). Figure 13 shows the average depth to water for various depth intervals by quarter township. Table 13 presents a tabulation of these data by section.

Long-Term Changes in Ground Water Levels

The only way to evaluate any long-term changes in elevations of the various water levels is through the use of hydrographs of certain key wells. A hydrograph is a graphical record of water level measurements, ideally taken during spring and fall of succeeding years, of a well for which the depth and construction details are known. The spring water level reading represents the highest level to which the ground water has recovered after the winter precipitation season; conversely, the fall measurement represents the lowest cyclic level to which the ground water level has dropped near the close of the summer pumping period.

Examination of long-term hydrographs gives a graphic record of slow declines, or recoveries, of levels of the various ground water bodies. Data of this type are available from 16 key wells throughout Sonoma County; hydrographs of these wells are presented on Figure 14. Most wells shown on Figure 14 have measurement records going back to 1950. A 25-year record from each well gives a good estimation of the nature of the ground water system that the well taps. For example, Well No. 6N/8W-7P2, shown on Figure 14, taps the Merced Formation and has a measurement record going back to the fall of 1949. The hydrograph indicates that there is essentially no change in water levels over the 26-year period, suggesting that the aquifer system which the well taps is being adequately recharged to meet its demand. In contrast,

Table 12

GROUND WATER BASINS AND WATER WELL DEVELOPMENT

Ground Water Basin and Subbasin	Basin and Subbasin Number	Area (square miles)	Area (square kilometers)	Number of Identified Water Wells
Alexander Valley	1-17.00	31.8	82.4	466
Alexander Area	1-17.01	23.3	60.3	321
Cloverdale Area	1-17.02	8.5	22.1	145
Santa Rosa Basin	1-18.00	126.7	328.0	4,006
Santa Rosa Plain	1-18.01	95.7	247.8	3,127
Healdsburg Area	1-18.02	27.4	70.9	495
Rincon Valley	1-18.03	3.6	9.3	384
Knights Valley	1-22.00	5.3	13.7	5
Kenwood Valley	1-23.00	6.2	16.1	57
Lower Russian River	1-98.00	9.3	24.1	69
Petaluma Valley	2-1.00	40.9	105.9	144
Sonoma Valley	2-2.02	49.5	128.2	382

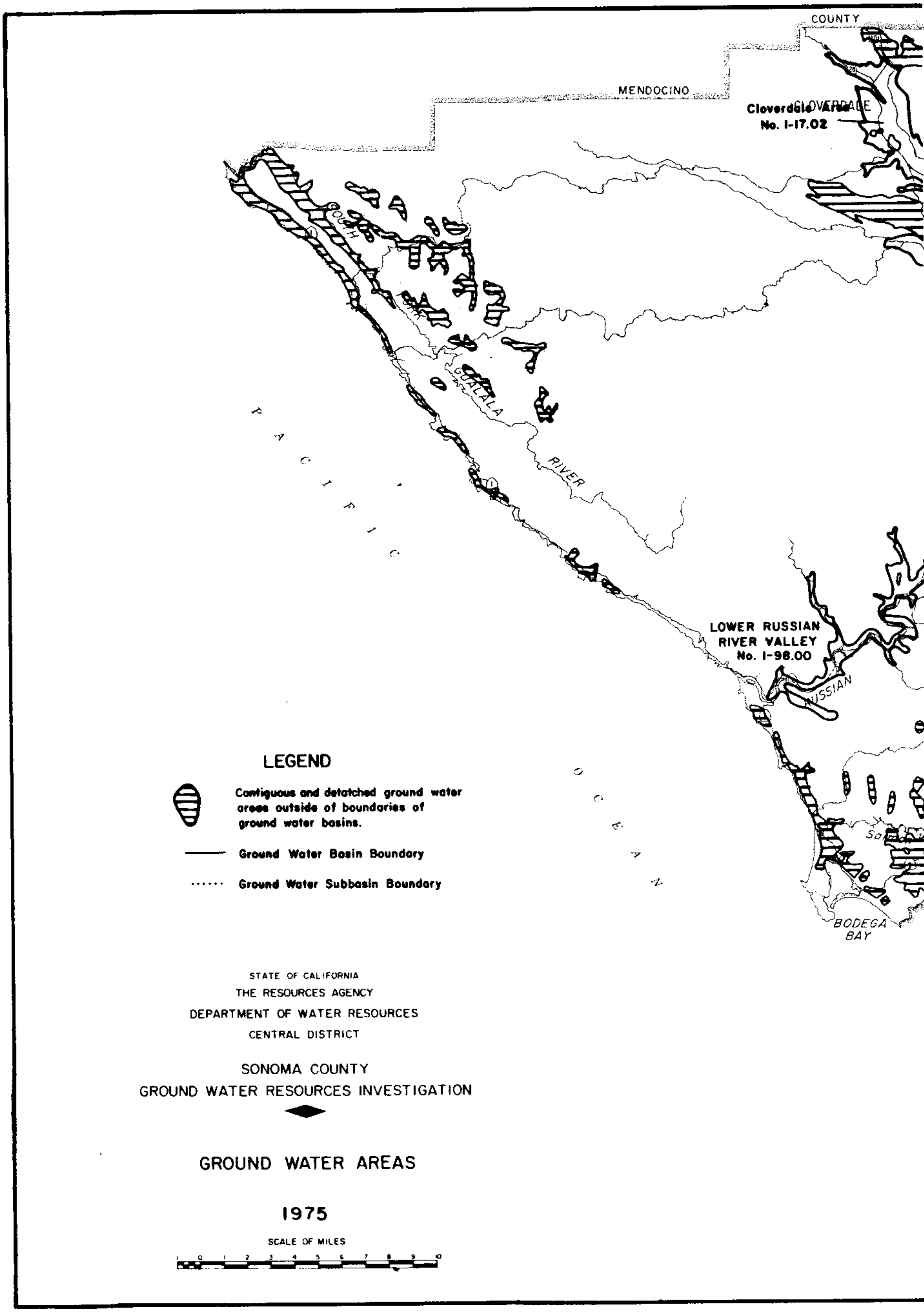
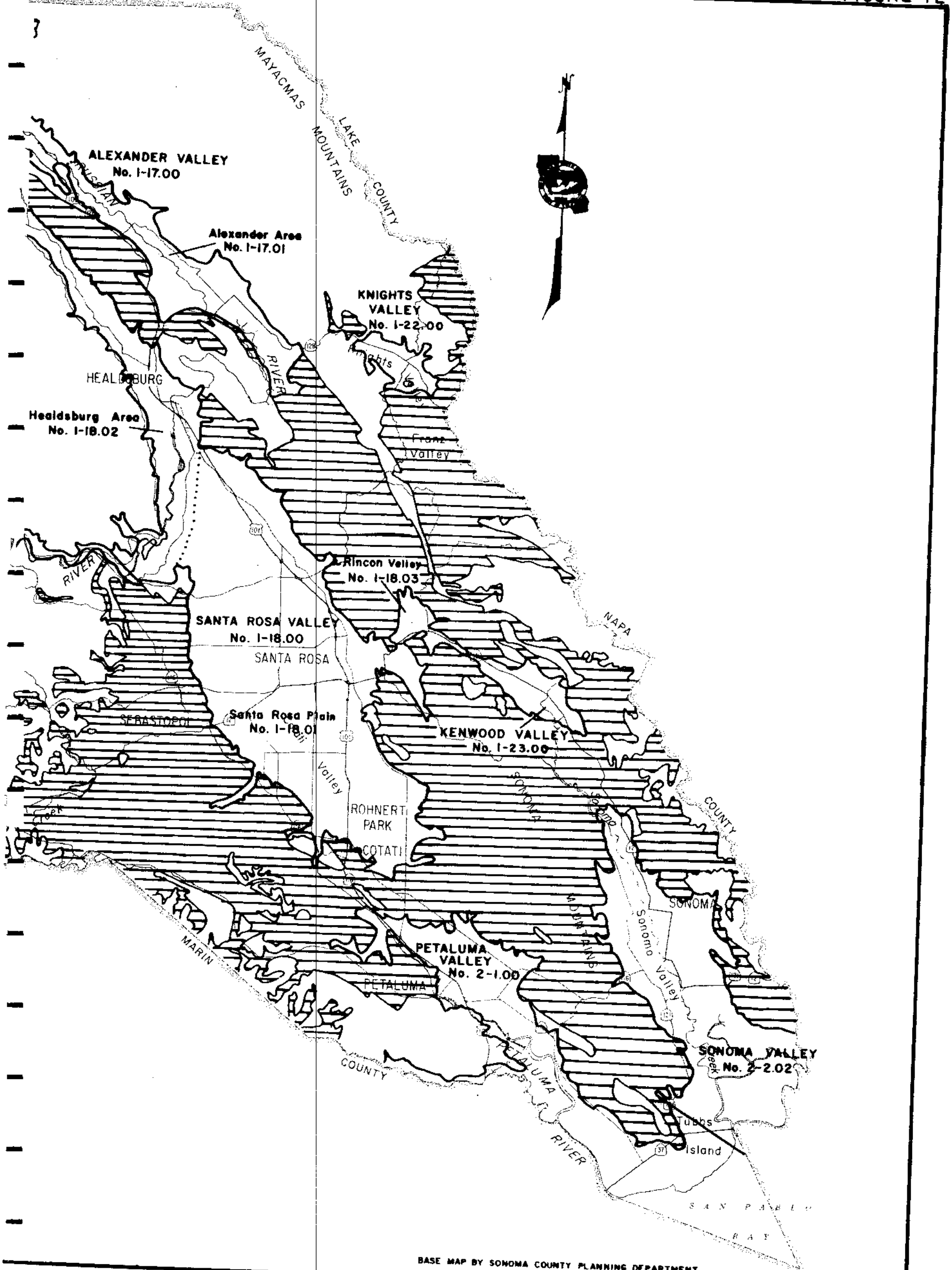
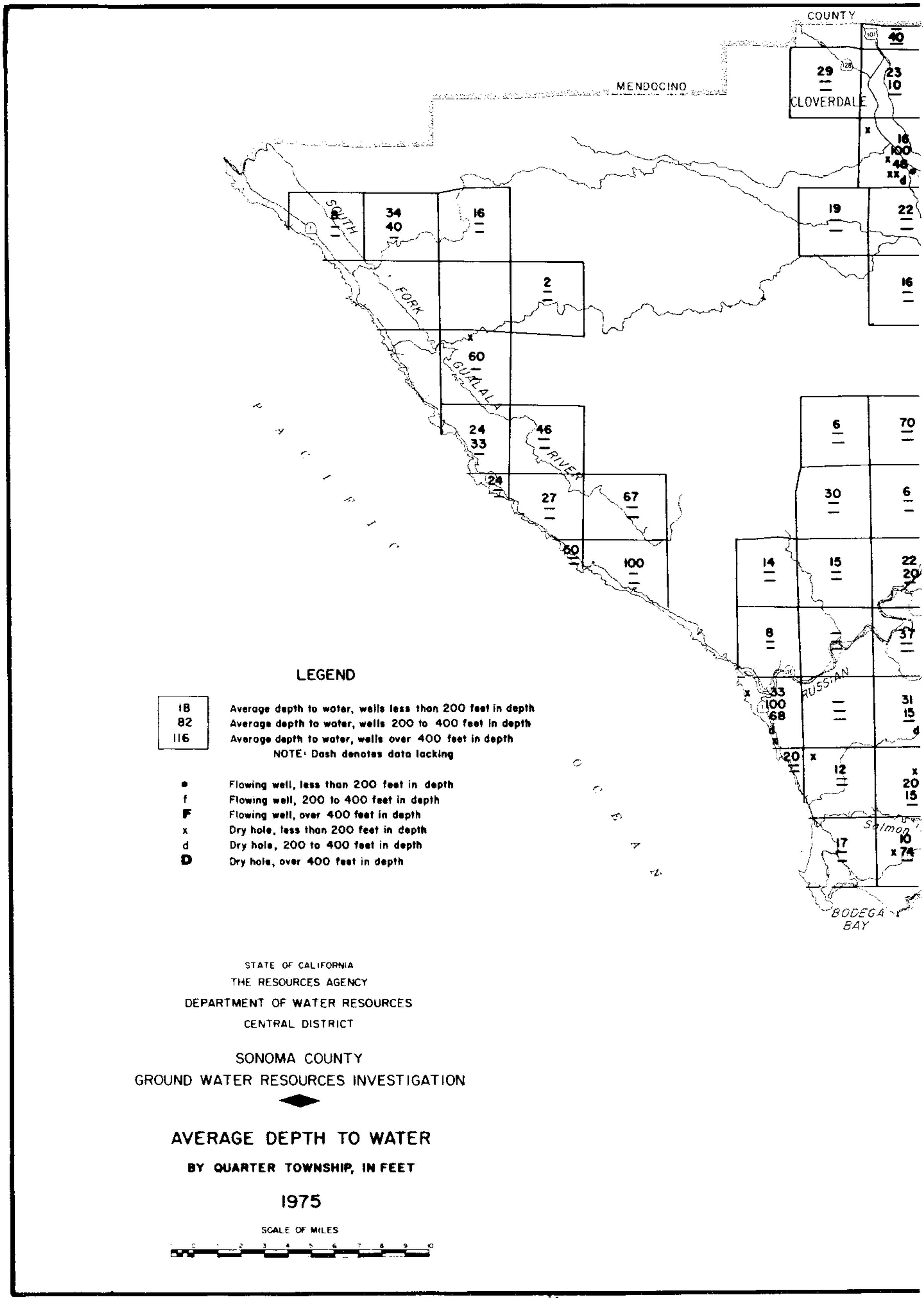

MENDOCINO
COUNTY
CLOVERDALE
Cloverdale Area
No. I-17.02
SOUTH
FORK
GUALALA
RIVER
P A C I F I C
O C E A N
LOWER RUSSIAN
RIVER VALLEY
No. I-98.00
RUSSIAN
BODEGA
BAY
LEGEND
Contiguous and detatched ground water areas outside of boundaries of ground water basins.
Ground Water Basin Boundary
Ground Water Subbasin Boundary
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT
SONOMA COUNTY
GROUND WATER RESOURCES INVESTIGATION
GROUND WATER AREAS
1975
SCALE OF MILES
1 0 1 2 3 4 5 6 7 8 9 10

FIGURE 12


MAYACMAS MOUNTAINS
LAKE COUNTY
ALEXANDER VALLEY
No. 1-17.00
Alexander Area
No. 1-17.01
KNIGHTS VALLEY
No. 1-22.00
HEALDSBURG
Healdsburg Area
No. 1-18.02
RIVER
Franz Valley
Rincon Valley
No. 1-18.03
SANTA ROSA VALLEY
No. 1-18.00
SANTA ROSA
SEBASTOPOL
Santa Rosa Plain
No. 1-18.01
NAPA COUNTY
KENWOOD VALLEY
No. 1-23.00
Valley
ROHNERT PARK
COTATI
SONOMA MOUNTAINS
Sonoma Valley
SONOMA
PETALUMA VALLEY
No. 2-1.00
PETALUMA
MARIN COUNTY
SONOMA VALLEY
No. 2-2.02
PETALUMA RIVER
Tubbs Island
SAN PABLO BAY
BASE MAP BY SONOMA COUNTY PLANNING DEPARTMENT



LEGEND

18	Average depth to water, wells less than 200 feet in depth
82	Average depth to water, wells 200 to 400 feet in depth
116	Average depth to water, wells over 400 feet in depth
	NOTE: Dash denotes data lacking

•	Flowing well, less than 200 feet in depth
f	Flowing well, 200 to 400 feet in depth
F	Flowing well, over 400 feet in depth
x	Dry hole, less than 200 feet in depth
d	Dry hole, 200 to 400 feet in depth
D	Dry hole, over 400 feet in depth

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

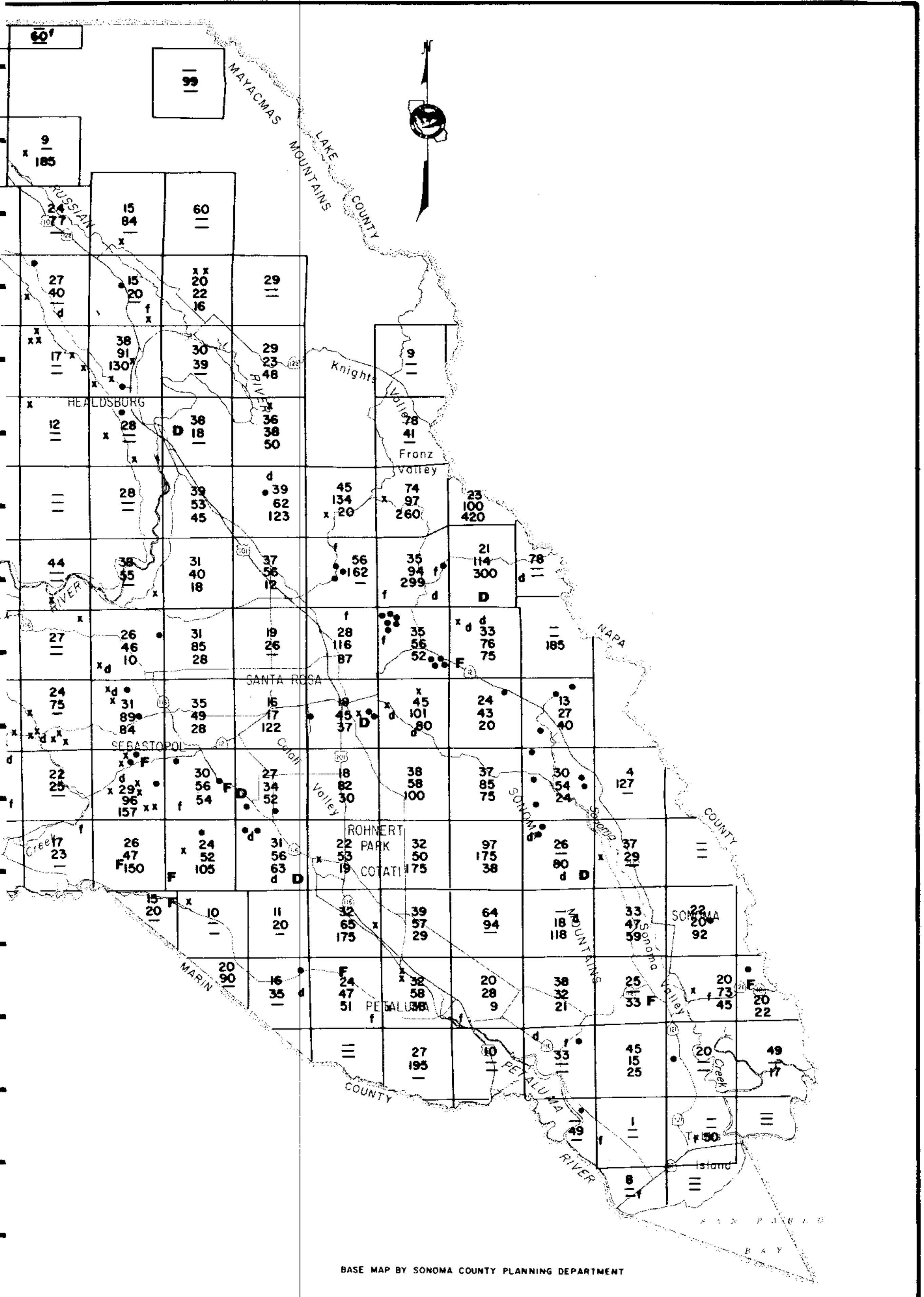
SONOMA COUNTY
GROUND WATER RESOURCES INVESTIGATION

AVERAGE DEPTH TO WATER

BY QUARTER TOWNSHIP, IN FEET

1975

SCALE OF MILES



BASE MAP BY SONOMA COUNTY PLANNING DEPARTMENT

Table 13

AVERAGE DEPTH TO WATER

Twp	Rge	Sec	Average Depth to Water by Well Depth											
			(In Feet)						(In Meters)					
			0-99	100-199	200-299	300-399	400-499	>500	0-30	30-61	61-91	91-121	121-152	>152
3	6	1	8	-	-	-	-	-	2.4	-	-	-	-	-
4	5	2	24	-	-	-	-	-	7.3	-	-	-	-	-
		6	8	16	-	-	-	-	2	4.9	-	-	-	-
		7	35	-	-	-	-	-	10.7	-	-	-	-	-
		12	17	-	-	-	-	-	5.2	-	-	-	-	-
		14	-	-	-	-	-	17	-	-	-	-	-	5.2
		19	-	-	-	-	85	15	-	-	-	-	25.9	4.6
4	6	1	-	45	15	-	25	-	-	13.7	4.6	-	7.6	-
		8	26	30	-	-	-	-	7.9	9.1	-	-	-	-
		17	-	43	-	-	-	-	-	13.1	-	-	-	-
		21	-	-	49	-	-	-	-	-	14.9	-	-	-
		26	-	1	-	-	-	-	-	0.3	-	-	-	-
4	7	2	2	15	-	-	-	-	0.6	4.6	-	-	-	-
		4	25	25	195	-	-	-	7.6	7.6	59.4	-	-	-
		5	30	-	-	-	-	-	9.1	-	-	-	-	-
		6	-	-	50	-	-	-	-	-	15.2	-	-	-
		14	18	-	-	-	-	-	5.5	-	-	-	-	-
		22	15	-	-	-	-	-	4.6	-	-	-	-	-
5	5	4	-	-	-	-	108	180	-	-	-	-	32.9	54.9
		7	13	-	8	10	62	-	4	-	2.4	3	18.9	-
		8	19	40	29	24	20	-	5.8	12.2	8.8	7.3	6.1	-
		9	-	20	40	-	-	-	-	6.1	12.2	-	-	-
		17	46	13	7	-	-	-	14	4	2.1	-	-	-
		18	14	13	-	20	-	-	4.3	4	-	6.1	-	-
		19	20	12	-	-	-	-	6.1	3.7	-	-	-	-
		20	10	28	33	-	-	-	3	8.5	10.1	-	-	-
		21	-	25	33	125	70	-	-	7.6	10.1	38.1	21.3	-
		22	-	-	-	20	22	-	-	-	-	6.1	6.7	-
		28	-	16	14	18	18	-	-	4.9	4.3	5.5	5.5	-
		29	30	19	100	-	70	-	9.1	5.8	30.5	-	21.3	-
		31	17	-	-	-	-	-	5.2	-	-	-	-	-
		33	10	35	-	-	-	-	3	10.7	-	-	-	-
5	6	1	40	23	48	36	-	30	12.2	7	14.6	11	-	9.1
		2	-	68	55	-	-	-	-	20.7	16.8	-	-	-
		3	-	7	30	-	114	-	-	2.1	9.1	-	34.8	-
		5	-	-	-	-	130	118	-	-	-	-	39.6	36
		9	-	-	5	-	-	-	-	-	1.5	-	-	-
		10	-	7	80	130	140	-	-	2.1	24.4	39.6	42.7	-
		11	64	35	-	-	-	-	19.5	10.7	-	-	-	-
		12	35	30	23	-	20	7	10.7	9.1	7	-	6.1	2.1
		13	25	30	30	9	-	40	7.6	9.1	9.1	2.7	-	12.2
		14	35	-	-	-	-	-	10.7	-	-	-	-	-
		15	-	-	30	-	-	-	-	-	9.1	-	-	-
		23	-	16	-	-	-	-	-	4.9	-	-	-	-
		24	-	-	-	-	-	12	-	-	-	-	-	3.7
		25	27	15	-	-	-	-	8.2	4.6	-	-	-	-
		26	31	3	-	-	-	-	9.5	.9	-	-	-	-
		29	-	-	40	-	-	-	-	-	12.2	-	-	-
		33	-	38	40	18	-	21	-	11.6	12.2	5.5	-	6.9
		36	30	-	-	-	-	-	9.1	-	-	-	-	-
5	7	3	-	70	-	-	-	-	-	21.3	-	-	-	-
		5	21	50	79	63	116	-	6.4	15.2	24.1	19.2	35.4	-
		6	25	56	-	-	-	-	7.6	17.1	-	-	-	-
		7	46	46	-	-	128	-	14	14	-	-	39	-
		8	-	62	-	-	-	-	-	18.9	-	-	-	-
		9	-	15	-	-	-	51	-	4.6	-	-	-	15.5
		10	-	95	-	-	-	-	-	29	-	-	-	-
		11	-	-	140	-	-	-	-	-	42.7	-	-	-
		15	-	26	82	60	-	-	-	7.9	25	18.3	-	-
		16	37	50	52	-	-	-	11.3	15.2	15.8	-	-	-
		17	-	60	40	60	10	-	-	18.3	12.2	18.3	3	-
		18	10	25	46	-	39	-	3	7.6	14	-	11.9	-
		19	70	46	82	-	-	-	21.3	14	25	-	-	-
		20	30	46	90	-	51	-	9.1	14	27.4	-	15.5	-
		21	-	29	-	-	-	-	-	8.8	-	-	-	-
		22	4	45	35	-	-	-	1.2	13.7	10.7	-	-	-
		25	-	-	-	-	11	-	-	-	-	-	3.4	-
5	7	26	-	13	-	-	-	7	-	4	-	-	-	2.1
		27	27	-	20	-	-	-	8.2	-	6.1	-	-	-
		28	18	-	-	-	24	-	5.5	-	-	-	7.3	-
		29	-	43	53	-	-	-	-	13.1	16.2	-	-	-
		30	35	29	30	-	-	-	10.7	8.8	9.1	-	-	-
		31	31	22	33	-	-	-	9.5	6.7	10.1	-	-	-
		32	20	28	110	-	-	-	6.1	8.5	33.5	-	-	-

Table 13 (continued)

Twp	Rge	Sec	Average Depth to Water by Well Depth (In Feet) 0-99	100-199	200-299	300-399	400-499	>500	(In Meters) 0-30	30-61	61-91	91-121	121-152	>152
5	7	33	8	24	10	-	-	-	2.4	7.3	3	-	-	-
		34	15	-	-	-	-	-	4.6	-	-	-	-	-
		35	18	-	-	-	-	-	5.5	-	-	-	-	-
5	8	1	28	44	96	-	-	-	8.5	13.4	29.3	-	-	-
		2	-	-	-	183	-	-	-	-	-	55.8	-	-
		3	-	32	-	-	-	-	-	9.8	-	-	-	-
		4	-	-	20	-	-	-	-	-	6.1	-	-	-
		10	-	20	-	-	-	-	-	6.1	-	-	-	-
		11	-	55	54	86	175	-	-	16.8	16.5	26.2	53.3	-
		12	25	-	-	16	-	-	7.6	-	-	4.9	-	-
		13	-	-	45	20	-	-	-	-	13.7	6.1	-	-
		14	-	37	40	-	-	-	-	11.3	12.2	-	-	-
		15	15	-	41	-	-	-	4.6	-	12.5	-	-	-
		16	-	18	-	-	-	-	-	5.5	-	-	-	-
		17	-	4	-	-	-	-	-	1.2	-	-	-	-
		21	-	32	35	-	-	-	-	9.8	10.7	-	-	-
		22	-	14	77	-	-	-	-	4.3	23.5	-	-	-
		23	20	31	51	14	-	-	6.1	9.4	15.5	4.3	-	-
		24	12	30	22	-	40	-	3.7	9.1	6.7	-	12.2	-
		25	12	45	-	-	-	-	3.7	13.7	-	-	-	-
		26	8	17	68	53	140	-	2.4	5.2	20.7	16.2	42.7	-
		27	-	20	75	-	14	10	-	6.1	22.9	-	4.3	3
		28	-	5	-	-	-	-	-	1.5	-	-	-	-
		30	10	-	-	-	-	-	3	-	-	-	-	-
		34	-	45	-	-	-	-	-	13.7	-	-	-	-
		36	20	40	12	-	-	-	6.1	12.2	3.7	-	-	-
5	9	4	-	15	6	35	-	-	-	4.6	1.8	10.7	-	-
		15	6	15	-	-	-	-	1.8	4.6	-	-	-	-
		23	-	20	90	-	-	-	-	6.1	27.4	-	-	-
6	6	1	-	-	-	180	-	-	-	-	-	54.9	-	-
		2	-	-	200	-	-	-	-	-	61	-	-	-
		3	-	-	-	200	-	-	-	-	-	61	-	-
		4	-	-	18	-	-	-	-	-	5.5	-	-	-
		5	-	30	-	-	-	-	-	9.1	-	-	-	-
		6	-	-	100	-	-	-	-	-	30.5	-	-	-
		7	-	32	45	45	20	-	-	9.8	13.7	13.7	6.1	-
		8	-	48	21	23	-	-	-	14.6	6.4	7	-	-
		9	9	-	15	49	32	-	2.7	-	4.6	14.9	9.8	-
		10	4	-	20	-	-	-	1.2	-	6.1	-	-	-
		15	4	-	-	-	-	-	1.2	-	-	-	-	-
		16	-	30	-	-	20	-	-	9.1	-	-	6.1	-
		17	-	-	70	190	-	-	-	-	21.3	57.9	-	-
		18	-	-	-	20	-	-	-	-	-	6.1	-	-
		20	-	26	-	-	-	-	-	7.9	-	-	-	-
		23	-	-	4	-	-	-	-	-	1.2	-	-	-
		26	-	40	26	-	-	-	-	12.2	7.9	-	-	-
		27	-	23	-	-	-	-	-	7	-	-	-	-
		33	-	-	-	-	-	80	-	-	-	-	-	24.4
		34	-	60	-	-	-	-	-	18.3	-	-	-	-
		35	-	24	81	-	-	-	-	7.3	24.7	-	-	-
6	7	2	-	68	92	34	-	-	-	20.7	28	10.4	-	-
		3	40	60	83	87	100	38	12.2	18.3	25.3	26.5	30.5	11.6
		4	-	31	45	73	65	-	-	9.4	13.7	22.3	19.8	-
		7	-	38	-	-	-	-	-	11.6	-	-	-	-
		8	-	-	-	-	-	134	-	-	-	-	-	40.8
		9	25	70	110	-	-	-	7.6	21.3	33.5	-	-	-
		10	20	27	97	-	-	-	6.1	8.2	29.6	-	-	-
		11	-	32	-	126	-	-	-	9.8	-	38.4	-	-
		12	-	54	-	-	-	-	-	16.5	-	-	-	-
		13	-	-	-	-	86	-	-	-	-	-	26.2	-
		14	14	22	-	-	-	-	4.3	6.7	-	-	-	-
		15	35	36	52	108	-	-	10.7	11	15.8	32.9	-	-
		16	-	-	40	-	-	-	-	-	12.2	-	-	-
		17	29	79	-	-	-	-	8.8	24.1	-	-	-	-
		18	15	-	24	-	-	-	4.6	-	7.3	-	-	-
		19	-	15	-	-	25	-	-	4.6	-	-	7.6	-
		20	-	22	36	-	-	-	-	6.7	11	-	-	-
		22	-	-	-	35	-	-	-	-	-	10.7	-	-
		23	-	-	-	-	-	75	-	-	-	-	-	22.9
		26	-	-	-	310	-	-	-	-	-	94.5	-	-
		27	-	97	181	-	-	20	-	29.6	55.2	-	-	6.1
		28	-	-	-	-	-	294	-	-	-	-	-	89.6
		29	-	-	65	-	-	-	-	-	19.8	-	-	-
		31	-	60	-	-	-	-	-	18.3	-	-	-	-
		32	-	-	-	-	200	-	-	-	-	-	61	-

Table 13 (continued)

Twp	Rge	Sec	Average Depth to Water by Well Depth											
			(In Feet)						(In Meters)					
			0-99	100-199	200-299	300-399	400-499	>500	0-30	30-61	61-91	91-121	121-152	>152
6	8	1	24	8	73	95	10	-	7.3	2.4	22.3	29	3	-
		2	16	18	-	-	-	49	4.9	5.5	-	-	-	14.9
		3	13	7	-	-	-	-	4	2.1	-	-	-	-
		4	12	18	40	-	-	-	3.7	5.5	12.2	-	-	-
		5	21	38	-	-	-	44	6.4	11.6	-	-	-	13.4
		6	15	12	-	-	-	-	4.6	3.7	-	-	-	-
		7	15	38	38	36	61	25	4.6	11.6	11.6	11	18.6	7.6
		8	30	10	30	-	-	40	9.1	3	9.1	-	-	12.2
		9	28	31	28	-	23	35	8.5	9.4	8.5	-	7	10.7
		10	11	21	-	-	-	-	3.4	6.4	-	-	-	-
		11	16	18	-	-	-	-	4.9	5.5	-	-	-	-
		12	17	18	-	80	-	-	5.2	5.5	-	24.4	-	-
		13	20	-	-	-	-	-	6.1	-	-	-	-	-
		14	31	18	-	-	-	-	9.4	5.5	-	-	-	-
		15	20	36	-	-	-	-	6.1	11	-	-	-	-
		16	39	45	-	-	125	60	11.9	13.7	-	-	38.1	18.3
		17	16	50	15	20	-	57	4.9	15.2	4.6	6.1	-	17.4
		18	18	43	60	41	-	53	5.5	13.1	18.3	12.5	-	16.2
		19	22	46	39	54	50	-	6.7	14	11.9	16.5	15.2	-
		20	21	45	65	70	-	-	6.4	13.7	19.8	21.3	-	-
		21	33	39	20	15	-	-	10	11.9	6.1	4.6	-	-
		22	17	18	-	-	-	-	5.2	5.5	-	-	-	-
		24	11	-	-	-	-	-	3.4	-	-	-	-	-
		25	8	23	-	-	-	18	2.4	7	-	-	-	5.5
		26	18	-	-	-	12	-	5.5	-	-	-	3.7	-
		27	20	30	40	38	35	-	6.1	9.1	12.2	11.6	10.7	-
		28	-	-	60	-	-	-	-	-	18.3	-	-	-
		29	18	34	53	64	40	-	5.5	10.4	16.2	19.5	12.2	-
		30	15	50	48	87	70	-	4.6	15.2	14.6	26.5	21.3	-
		31	17	41	-	100	-	-	5.2	12.5	-	30.5	-	-
		32	-	21	78	-	-	120	-	6.4	23.8	-	-	36.6
		33	35	30	25	-	35	-	10.7	9.1	7.6	-	10.7	-
		34	-	32	-	-	-	-	-	9.8	-	-	-	-
		35	29	45	80	-	-	-	8.8	13.7	24.4	-	-	-
		36	15	20	-	-	-	30	4.6	6.1	-	-	-	9.1
6	9	1	18	22	19	-	40	-	5.5	6.7	5.8	-	12.2	-
		2	32	42	64	100	83	36	9.8	12.8	19.5	30.5	25.3	11
		3	15	29	42	30	30	-	4.6	8.8	12.8	9.1	9.1	-
		4	21	-	75	127	210	-	6.4	-	22.9	38.7	64	-
		5	11	27	110	127	-	-	3.4	8.2	33.5	38.7	-	-
		6	14	53	68	-	-	-	4.3	16.2	30.7	-	-	-
		7	7	38	141	-	-	-	2.1	11.6	43	-	-	-
		8	28	32	111	190	-	-	8.5	9.8	33.8	57.9	-	-
		9	26	51	104	126	190	-	7.9	15.5	31.7	38.4	57.9	-
		10	17	40	44	112	43	-	5.2	12.2	13.4	34.1	13.1	-
		11	20	49	59	58	55	80	6.1	14.9	18	17.7	16.8	24.4
		12	25	32	32	39	42	47	7.6	9.8	9.8	11.9	12.8	14.3
		13	24	32	52	44	60	60	7.3	9.8	15.8	13.4	18.3	18.3
		14	28	45	63	64	71	-	8.5	13.7	19.2	19.5	21.6	-
		15	-	41	67	-	-	-	-	12.5	20.4	-	-	-
		16	9	34	32	-	-	-	2.7	10.4	9.8	-	-	-
		17	-	46	58	-	72	-	-	14	17.7	-	21.9	-
		18	18	41	74	105	-	-	5.5	12.5	22.6	32	-	-
		20	40	36	92	-	-	-	12.2	11	28	-	-	-
		21	33	49	-	-	150	-	10	14.9	-	-	45.7	-
		22	15	-	8	-	-	60	4.6	-	2.4	-	-	18.3
		23	17	51	57	140	-	-	5.2	15.5	17.4	42.7	-	-
		24	-	35	12	-	-	-	-	10.7	3.7	-	-	-
		25	-	32	-	-	-	-	-	9.8	-	-	-	-
		26	-	-	-	200	-	-	-	-	-	61	-	-
		27	30	-	60	-	150	-	9.1	-	18.3	-	45.7	-
		32	5	-	-	14	-	-	1.5	-	-	4.3	-	-
		33	6	15	35	-	-	-	1.8	4.6	10.7	-	-	-
		34	-	22	-	-	-	-	-	6.7	-	-	-	-
6	10	1	28	32	55	-	-	-	8.5	9.8	16.8	-	-	-
		2	15	-	-	-	-	-	4.6	-	-	-	-	-
		3	15	-	-	-	-	-	4.6	-	-	-	-	-
		4	20	-	-	-	-	-	6.1	-	-	-	-	-
		5	19	-	-	15	-	-	5.8	-	-	4.6	-	-
		6	14	-	-	-	-	-	4.3	-	-	-	-	-
		8	27	9	-	-	-	-	8.2	2.7	-	-	-	-
		9	23	10	-	-	-	-	7	3	-	-	-	-
		12	11	38	-	-	-	-	3.4	11.6	-	-	-	-
		13	16	-	25	-	-	-	4.9	-	7.6	-	-	-
		16	37	-	-	-	-	-	11.3	-	-	-	-	-
		21	16	12	101	-	-	-	4.9	3.7	30.8	-	-	-
		22	-	-	20	-	-	-	-	-	6.1	-	-	-
		23	20	-	45	-	-	-	6.1	-	13.7	-	-	-
		24	-	15	-	-	-	-	-	4.6	-	-	-	-
		25	-	17	-	3	-	-	-	5.2	-	.9	-	-
		27	7	-	-	-	-	-	2.1	-	-	-	-	-
		29	2	-	-	-	-	-	.6	-	-	-	-	-
		30	-	-	47	-	-	-	-	-	14.3	-	-	-
		36	-	28	-	-	-	-	-	8.5	-	-	-	-

Table 13 (continued)

Twp	Rge	Sec	Average Depth to Water by Well Depth (In Feet) 0-99	100-199	200-299	300-399	400-499	>500	(In Meters) 0-30	30-61	61-91	91-121	121-152	>152
6	11	4	20	-	-	-	-	-	6.1	-	-	-	-	-
		14	11	-	-	-	-	-	3.4	-	-	-	-	-
		15	14	-	-	-	-	-	4.3	-	-	-	-	-
		22	28	-	-	-	-	-	8.5	-	-	-	-	-
		23	10	-	-	-	-	-	3	-	-	-	-	-
		26	-	13	-	-	-	-	-	4	-	-	-	-
		34	10	-	-	-	-	-	3	-	-	-	-	-
		36	13	-	-	-	-	-	4	-	-	-	-	-
7	6	18	-	-	-	-	-	185	-	-	-	-	-	56.4
		19	-	16	-	35	50	-	-	4.9	-	10.7	15.2	-
		20	12	7	-	-	-	-	3.7	2.1	-	-	-	-
		29	-	15	-	-	-	-	-	4.6	-	-	-	-
		30	4	6	12	35	30	-	1.2	1.8	3.7	10.7	9.1	-
		31	-	40	-	-	-	-	-	12.2	-	-	-	-
		32	10	3	-	-	-	-	3	.9	-	-	-	-
7	7	1	-	5	-	-	-	-	-	1.5	-	-	-	-
		3	44	38	-	-	-	-	13.4	11.6	-	-	-	-
		5	20	43	58	68	-	12	6.1	13.1	17.7	30.7	-	3.7
		6	21	37	24	42	-	-	6.4	11.3	7.3	12.8	-	-
		7	20	40	37	15	-	-	6.1	12.2	11.3	4.6	-	-
		8	17	47	50	49	69	72	5.2	14.3	15.2	14.9	21	21.9
		9	-	51	53	117	-	86	-	15.5	16.2	35.7	-	26.2
		10	25	62	90	122	-	-	7.6	18.9	27.4	37.2	-	-
		15	13	46	27	65	75	-	4	14	8.2	19.8	62.9	-
		16	12	71	42	-	20	-	3.7	21.6	12.8	-	6.1	-
		17	-	-	97	76	-	-	-	-	29.6	23.2	-	-
		18	28	47	57	-	-	-	8.5	14.3	17.4	-	-	-
		19	35	26	-	-	-	80	10.7	7.9	-	-	-	24.4
		20	55	55	144	53	-	-	16.8	16.8	43.9	16.2	-	-
		23	-	-	70	-	-	-	-	-	21.3	-	-	-
		24	24	-	-	-	-	20	7.3	-	-	-	-	6.1
		29	-	-	-	27	-	-	-	-	-	8.2	-	-
		30	40	30	99	210	-	-	12.2	9.1	30.2	64	-	-
		32	18	42	74	-	-	-	5.5	12.8	22.6	-	-	-
		33	-	104	-	-	-	-	-	31.7	-	-	-	-
		34	-	-	35	-	-	-	-	-	10.7	-	-	-
		36	-	-	25	-	-	-	-	-	7.6	-	-	-
7	8	1	-	50	75	-	-	-	-	15.2	22.9	-	-	-
		2	20	41	163	-	-	-	6.1	12.5	49.7	-	-	-
		3	13	37	150	-	-	-	4	11.3	45.7	-	-	-
		4	16	19	16	-	-	-	4.9	5.8	4.9	-	-	-
		5	18	12	-	-	-	-	5.5	3.7	-	-	-	-
		6	26	24	-	26	-	-	7.9	7.3	-	7.9	-	-
		7	20	33	47	-	-	-	6.1	10	14.3	-	-	-
		8	17	26	30	-	-	-	5.2	7.9	9.1	-	-	-
		9	17	21	-	-	-	-	5.2	6.4	-	-	-	-
		10	16	21	8	9	-	80	4.9	6.4	2.4	2.7	-	24.4
		11	22	40	150	-	-	-	6.7	12.2	45.7	-	-	-
		12	24	56	103	340	-	-	7.3	17.1	31.4	103.6	-	-
		13	16	21	-	-	-	-	4.9	6.4	-	-	-	-
		14	20	49	-	-	-	-	6.1	14.9	-	-	-	-
		15	13	17	45	-	-	94	4	5.2	13.7	-	-	28.7
		16	17	13	20	15	-	-	5.2	4	6.1	4.6	-	-
		17	18	27	-	30	-	-	5.5	8.2	-	9.1	-	-
		18	19	27	-	-	-	-	5.8	8.2	-	-	-	-
		19	15	23	10	-	-	-	4.6	7	3	-	-	-
		20	10	8	-	18	-	-	3	2.4	-	5.5	-	-
		21	23	16	-	25	8	-	7	4.9	-	7.6	2.4	-
		22	14	20	-	-	-	-	4.3	6.1	-	-	-	-
		23	15	17	-	-	-	-	4.6	5.2	-	-	-	-
		24	13	26	50	35	-	33	4	7.9	15.2	10.7	-	10
		25	17	28	71	62	-	-	5.2	8.5	21.6	18.9	-	-
		26	12	16	-	-	-	-	3.7	4.9	-	-	-	-
		27	16	15	40	-	40	-	4.9	4.6	12.2	-	12.2	-
		28	14	-	18	-	-	-	4.3	-	5.5	-	-	-
		29	14	16	-	-	-	10	4.3	4.9	-	-	-	3
		30	18	23	6	-	-	38	5.5	7	1.8	-	-	11.6
		31	14	-	-	-	-	-	4.3	-	-	-	-	-
		32	12	3	-	-	-	-	3.7	.9	-	-	-	-
		33	11	19	23	-	-	430	3.4	5.8	7	-	-	131.1
		34	12	30	-	-	-	-	3.7	9.1	-	-	-	-
		35	22	27	30	-	-	37	6.7	8.2	9.1	-	-	11.3
		36	20	-	25	-	-	-	6.1	-	7.6	-	-	-
7	9	1	-	27	110	95	-	-	-	8.2	33.5	29	-	-
		2	29	29	60	125	-	-	8.8	8.8	18.3	38.1	-	-
		3	38	-	41	-	-	-	11.6	-	12.5	-	-	-
		4	34	-	-	-	-	-	10.4	-	-	-	-	-
		5	20	16	-	-	-	-	6.1	4.9	-	-	-	-

Table 13 (continued)

Twp	Rge	Sec	Average Depth to Water by Well Depth (In Feet) 0-99	100-199	200-299	300-399	400-499	>500	(In Meters) 0-30	30-61	61-91	91-121	121-152	>152
7	9	6	19	-	-	-	-	-	5.8	-	-	-	-	-
		7	11	-	-	-	-	-	3.4	-	-	-	-	-
		8	22	30	51	65	-	-	6.7	9.1	15.5	19.8	-	-
		9	-	48	55	50	-	-	-	14.6	16.8	15.2	-	-
		10	28	48	46	115	-	-	8.5	14.6	14	35.1	-	-
		11	25	40	25	24	-	-	7.6	12.2	7.6	7.3	-	-
		12	21	20	100	-	-	-	6.4	6.1	30.5	-	-	-
		13	21	31	37	-	55	2	6.4	9.4	11.3	-	16.8	.6
		14	27	42	60	-	-	-	8.2	12.8	18.3	-	-	-
		15	35	42	69	288	-	-	10.7	12.8	21	87.8	-	-
		16	35	43	67	55	-	-	10.7	13.1	20.4	16.8	-	-
		17	31	23	18	5	10	-	9.4	7	5.5	1.5	3	-
		18	27	8	-	-	-	-	8.2	2.4	-	-	-	-
		19	18	19	-	-	-	-	5.5	5.8	-	-	-	-
		20	26	52	-	-	-	-	7.9	15.8	-	-	-	-
		21	9	32	71	30	85	-	2.7	9.8	21.6	9.1	25.9	-
		22	30	25	30	60	43	-	9.1	7.6	9.1	18.3	13.1	-
		23	32	48	41	-	-	17	9.8	14.6	12.5	-	-	5.2
		24	40	29	-	-	-	-	12.2	8.8	-	-	-	-
		25	18	19	21	12	-	-	5.5	5.8	6.4	3.7	-	-
		26	26	-	-	87	33	-	7.9	-	-	26.5	10	-
		27	41	42	69	75	-	19	12.5	12.8	21	22.9	-	5.8
		28	20	60	80	80	83	12	6.1	18.3	24.4	24.4	25.3	3.7
		29	-	29	40	92	-	-	-	8.8	12.2	28	-	-
		30	23	37	-	-	-	-	7	11.3	-	-	-	-
		31	36	36	86	170	-	-	11	11	26.2	51.8	-	-
		32	-	25	75	156	180	-	-	7.6	62.9	47.5	54.9	-
		33	21	53	110	77	50	-	6.4	16.2	33.5	23.5	15.2	-
		34	29	34	37	34	36	48	8.8	10.4	11.3	10.4	11	14.6
		35	53	56	35	22	-	-	16.2	17.1	10.7	6.7	-	-
		36	25	30	12	-	-	-	7.6	9.1	3.7	-	-	-
7	10	1	17	-	-	-	-	-	5.2	-	-	-	-	-
		2	18	-	-	-	-	-	5.5	-	-	-	-	-
		3	-	80	-	-	-	-	-	24.4	-	-	-	-
		4	15	-	-	-	-	-	4.6	-	-	-	-	-
		5	-	42	-	-	-	-	-	12.8	-	-	-	-
		6	-	54	-	-	-	-	-	16.5	-	-	-	-
		10	10	30	-	-	-	-	3	9.1	-	-	-	-
		11	-	49	-	-	-	-	-	14.9	-	-	-	-
		13	6	-	-	-	-	-	1.8	-	-	-	-	-
		14	5	-	-	-	-	-	1.5	-	-	-	-	-
		20	5	-	-	-	-	-	1.5	-	-	-	-	-
		21	12	-	-	-	-	-	3.7	-	-	-	-	-
		23	21	40	-	-	-	-	6.4	12.2	-	-	-	-
		24	18	-	160	-	-	-	5.5	-	48.8	-	-	-
		25	18	19	-	-	-	-	5.5	5.8	-	-	-	-
		26	20	45	-	-	-	-	6.1	13.7	-	-	-	-
		27	-	6	-	-	-	-	-	1.8	-	-	-	-
		28	14	80	-	-	-	-	4.3	24.4	-	-	-	-
		29	25	30	-	-	-	-	7.6	9.1	-	-	-	-
		30	-	78	-	-	-	-	-	23.8	-	-	-	-
		32	16	-	-	-	-	-	4.9	-	-	-	-	-
		33	24	26	15	-	-	-	7.3	7.9	4.6	-	-	-
		34	14	-	35	-	-	-	4.3	-	10.7	-	-	-
		35	14	43	-	-	-	-	4.3	13.1	-	-	-	-
		36	15	40	30	-	-	-	4.6	12.2	9.1	-	-	-
7	11	2	14	-	-	-	-	-	4.3	-	-	-	-	-
		3	15	-	-	-	-	-	4.6	-	-	-	-	-
		10	22	-	-	-	-	-	6.7	-	-	-	-	-
		12	38	-	-	-	-	-	11.6	-	-	-	-	-
		15	23	120	-	-	-	-	7	36.6	-	-	-	-
		18	8	-	-	-	-	-	2.4	-	-	-	-	-
		19	42	61	-	-	-	-	12.8	18.6	-	-	-	-
		29	18	-	100	-	68	-	5.5	-	30.5	-	20.7	-
		32	11	-	-	-	-	-	3.4	-	-	-	-	-
8	6	19	42	-	-	-	-	-	12.8	-	-	-	-	-
		30	70	33	-	-	-	-	21.3	10.1	-	-	-	-
		32	-	90	-	-	-	-	-	27.4	-	-	-	-
8	7	1	-	-	100	-	-	-	-	-	30.5	-	-	-
		3	-	-	-	-	-	420	-	-	-	-	-	128
		4	-	-	45	-	330	-	-	-	13.7	-	100.6	-
		7	14	57	115	-	-	-	4.3	17.4	35.1	-	-	-
		8	-	117	-	-	-	-	-	35.7	-	-	-	-
		9	-	-	80	-	-	-	-	-	24.4	-	-	-
		10	30	16	-	-	-	-	9.1	4.9	-	-	-	-
		16	-	106	170	-	190	-	-	32.3	51.8	-	57.9	-
		17	-	-	75	-	-	-	-	-	62.9	-	-	-
		20	-	27	-	205	-	-	-	8.2	-	62.5	-	-
		25	40	-	-	-	-	-	12.2	-	-	-	-	-

Table 13 (continued)

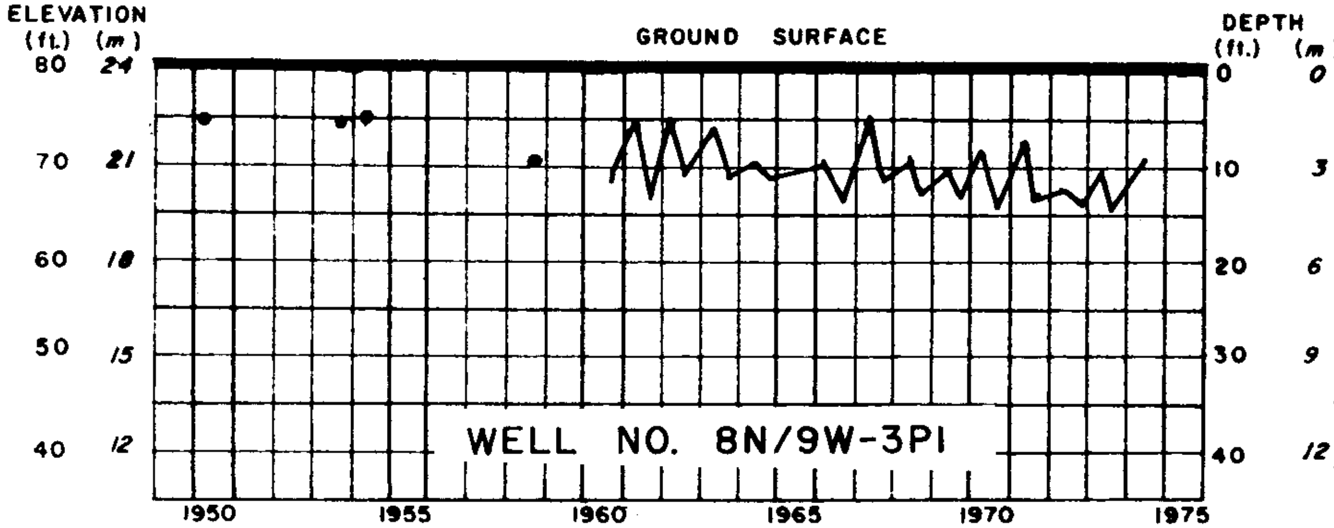
Twp	Rge	Sec	Average Depth to Water by Well Depth (In Feet) 0-99	100-199	200-299	300-399	400-499	>500	(In Meters) 0-30	30-61	61-91	91-121	121-152	>152
8	7	26	-	-	114	-	-	-	-	-	34.7	-	-	-
		27	12	30	-	-	300	-	3.7	9.1	-	-	91.4	-
		29	-	13	-	-	-	-	-	4	-	-	-	-
		31	-	30	35	64	138	460	-	9.1	10.7	19.5	42.1	140.2
		32	-	70	70	-	-	-	-	21.3	21.3	-	-	-
		34	-	12	-	-	-	-	-	3.7	-	-	-	-
		35	-	10	-	-	-	-	-	3	-	-	-	-
8	8	1	-	-	-	220	-	-	-	-	-	67.1	-	-
		5	15	23	45	-	-	-	4.6	7	13.7	-	-	-
		6	-	-	60	20	-	-	-	-	18.3	6.1	-	-
		7	-	75	24	-	-	-	-	62.9	7.3	-	-	-
		8	62	28	147	-	-	-	18.9	8.5	44.8	-	-	-
		9	29	-	-	-	-	-	8.8	-	-	-	-	-
		11	18	29	-	-	-	-	5.5	8.8	-	-	-	-
		12	44	-	-	15	-	20	13.4	-	-	4.6	-	6.1
		14	-	90	167	-	-	-	-	27.4	50.9	-	-	-
		17	-	49	-	110	246	69	-	14.9	-	33.5	75	21
		18	29	42	46	45	53	-	8.8	12.8	14	13.7	16.2	-
		19	30	41	11	36	-	-	9.1	12.5	3.4	11	-	-
		20	34	53	34	-	-	-	10.4	16.2	10.4	-	-	-
		21	88	65	222	-	-	-	26.8	19.8	67.7	-	-	-
		22	-	107	-	-	-	-	-	32.6	-	-	-	-
		23	50	97	110	290	-	-	15.2	29.6	33.5	88.4	-	-
		25	10	-	144	147	-	-	3	-	43.9	44.8	-	-
		26	15	65	143	210	-	-	4.6	19.8	43.6	64	-	-
		27	16	166	230	-	-	-	4.9	50.6	70.1	-	-	-
		28	23	-	-	-	-	-	7	-	-	-	-	-
		29	25	50	96	36	-	-	7.6	15.2	29.3	11	-	-
		30	21	21	17	33	-	-	6.4	6.4	5.2	10	-	-
		31	16	22	-	-	-	-	4.9	6.7	-	-	-	-
		32	17	65	19	-	-	-	5.2	19.8	5.8	-	-	-
		33	31	27	-	-	-	12	9.4	8.2	-	-	-	3.7
		34	20	17	20	-	-	-	6.1	5.2	6.1	-	-	-
		36	-	52	-	-	-	-	-	15.8	-	-	-	-
8	9	1	19	45	69	80	-	-	5.8	13.7	21	24.4	-	-
		2	35	42	-	-	-	-	10.7	12.8	-	-	-	-
		3	27	20	40	-	-	-	8.2	6.1	12.2	-	-	-
		4	17	-	-	-	-	-	5.2	-	-	-	-	-
		5	15	20	-	-	-	-	4.6	6.1	-	-	-	-
		7	18	-	-	-	-	-	5.5	-	-	-	-	-
		9	18	-	-	-	-	-	5.5	-	-	-	-	-
		10	59	50	-	-	-	-	18	15.2	-	-	-	-
		11	37	48	53	-	-	52	11.3	14.6	16.2	-	-	15.8
		12	35	39	20	-	-	30	10.7	11.9	6.1	-	-	9.1
		13	36	40	33	-	47	-	11	12.2	10	-	14.3	-
		14	30	45	40	-	-	50	9.1	13.7	12.2	-	-	15.2
		15	38	50	87	-	-	-	11.6	15.2	26.5	-	-	-
		16	80	-	-	-	-	-	24.4	-	-	-	-	-
		19	66	-	-	-	-	-	20.1	-	-	-	-	-
		20	18	-	-	-	-	-	5.5	-	-	-	-	-
		21	20	-	-	-	-	-	6.1	-	-	-	-	-
		22	27	41	40	40	-	-	8.2	12.5	12.2	12.2	-	-
		23	32	26	-	-	18	-	9.8	7.9	-	-	5.5	-
		24	32	30	37	30	-	-	9.8	9.1	11.3	9.1	-	-
		25	30	21	52	-	-	-	9.1	6.4	15.8	-	-	-
		26	31	34	-	-	-	-	9.4	10.4	-	-	-	-
		27	27	65	-	71	2	-	8.2	19.8	-	21.6	.6	-
		28	33	60	-	-	-	-	10	18.3	-	-	-	-
		29	33	15	-	-	-	-	10	4.6	-	-	-	-
		31	24	33	-	-	-	-	7.3	10	-	-	-	-
		32	20	40	60	-	-	-	6.1	12.2	18.3	-	-	-
		33	21	-	65	-	-	-	6.4	-	19.8	-	-	-
		36	10	-	12	-	-	-	3	-	3.7	-	-	-
8	10	17	6	-	-	-	-	-	1.8	-	-	-	-	-
		19	10	-	-	-	-	-	3	-	-	-	-	-
		20	10	-	-	-	-	-	3	-	-	-	-	-
		21	30	-	-	-	-	-	9.1	-	-	-	-	-
		22	-	102	-	-	-	-	-	31.1	-	-	-	-
		25	17	-	-	-	-	-	5.2	-	-	-	-	-
		26	24	-	-	-	-	-	7.3	-	-	-	-	-
		28	8	-	-	-	-	-	2.4	-	-	-	-	-
		29	9	-	-	-	-	-	2.7	-	-	-	-	-
		30	16	70	20	-	-	-	4.9	21.3	6.1	-	-	-
		31	25	25	-	-	-	-	7.6	7.6	-	-	-	-
		32	6	45	-	-	-	-	1.8	13.7	-	-	-	-
		33	11	-	-	-	-	-	3.4	-	-	-	-	-
		34	20	100	-	-	-	-	6.1	30.5	-	-	-	-
		35	3	-	-	-	-	-	.9	-	-	-	-	-

Table 13 (continued)

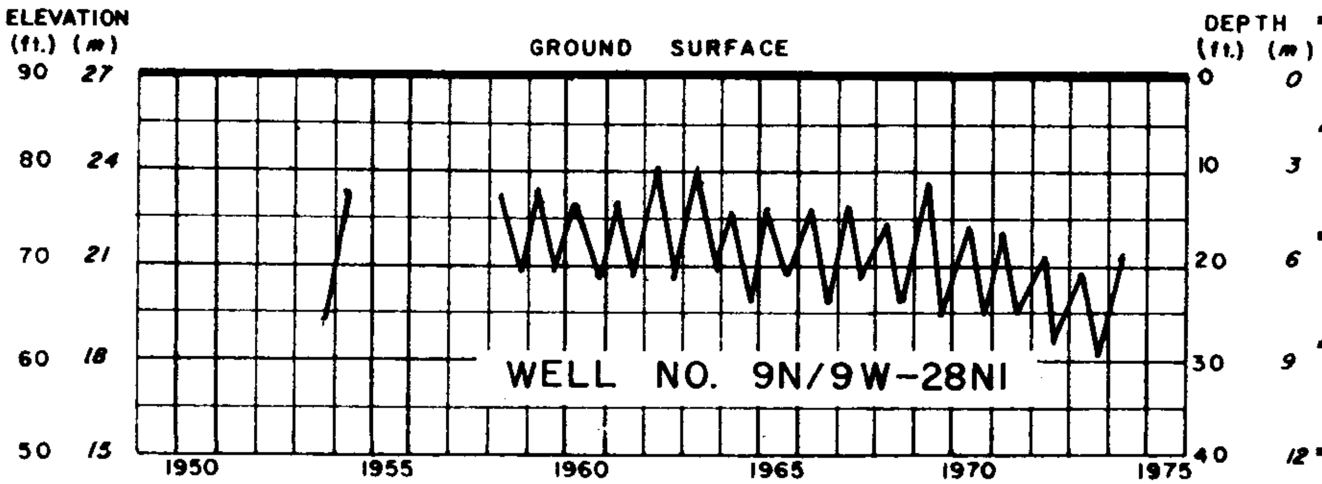
Twp	Rge	Sec	Average Depth to Water by Well Depth (In Feet) 0-99	100-199	200-299	300-399	400-499	>500	(In Meters) 0-30	30-61	61-91	91-121	121-152	>152
8	11	11	30	-	-	-	-	-	9.1	-	-	-	-	-
		21	14	-	-	-	-	-	4.3	-	-	-	-	-
		22	15	-	-	-	-	-	4.6	-	-	-	-	-
		27	15	-	-	-	-	-	4.6	-	-	-	-	-
		34	22	-	-	-	-	-	6.7	-	-	-	-	-
8	12	7	-	67	-	-	-	-	-	20.4	-	-	-	-
		21	-	100	-	-	-	-	-	30.5	-	-	-	-
8	13	2	28	-	-	-	-	-	8.5	-	-	-	-	-
		9	16	31	-	-	-	-	4.9	9.4	-	-	-	-
		10	7	-	-	-	-	-	2.1	-	-	-	-	-
		12	17	45	-	-	-	-	5.2	13.7	-	-	-	-
		13	60	-	-	-	-	-	18.3	-	-	-	-	-
		14	16	19	-	-	-	-	4.9	5.8	-	-	-	-
		24	-	50	-	-	-	-	-	15.2	-	-	-	-
9	7	18	9	-	-	-	-	-	2.7	-	-	-	-	-
		19	-	50	40	70	-	-	-	15.2	12.2	21.3	-	-
		28	25	-	-	-	-	-	7.6	-	-	-	-	-
		29	-	-	-	23	-	-	-	-	-	7	-	-
		31	-	210	40	30	-	-	-	64	12.2	9.1	-	-
		32	28	-	-	-	-	-	8.5	-	-	-	-	-
9	8	6	56	38	20	25	-	35	17.1	11.6	6.1	7.6	-	10.7
		7	15	-	-	-	-	-	4.6	-	-	-	-	-
		8	-	-	25	-	-	-	-	-	7.6	-	-	-
		17	13	36	-	-	20	90	4	11	-	-	6.1	27.4
		18	15	-	-	-	-	-	4.6	-	-	-	-	-
		20	14	29	30	-	-	-	4.3	8.8	9.1	-	-	-
		21	-	-	-	45	-	-	-	-	-	13.7	-	-
		28	-	-	-	-	50	-	-	-	-	-	15.2	-
		29	22	62	-	-	-	-	6.7	18.9	-	-	-	-
		31	-	75	-	-	-	-	-	22.9	-	-	-	-
		32	3	-	-	-	-	-	.9	-	-	-	-	-
		33	-	50	-	-	-	-	-	15.2	-	-	-	-
9	9	1	10	33	22	-	15	-	3	10.1	6.7	-	4.6	-
		2	26	22	-	25	-	-	7.9	6.7	-	7.6	-	-
		3	9	45	70	-	-	-	2.7	13.7	21.3	-	-	-
		4	36	34	175	-	-	-	11	10.4	53.3	-	-	-
		5	-	30	45	-	-	-	-	9.1	13.7	-	-	-
		6	27	150	46	-	-	-	8.2	45.7	14	-	-	-
		7	13	41	-	168	-	-	4	12.5	-	51.2	-	-
		8	36	65	20	-	-	-	11	19.8	6.1	-	-	-
		10	-	80	-	-	-	-	-	24.4	-	-	-	-
		12	29	-	-	-	-	-	8.8	-	-	-	-	-
		15	19	30	-	-	-	-	5.8	9.1	-	-	-	-
		17	13	20	-	-	-	-	4	6.1	-	-	-	-
		18	17	15	-	-	130	-	5.2	4.6	-	-	39.6	-
		19	14	-	-	-	-	-	4.3	-	-	-	-	-
		20	19	27	-	-	-	-	5.8	8.2	-	-	-	-
		21	33	45	-	-	-	-	10.1	13.7	-	-	-	-
		22	30	-	-	-	-	-	9.1	-	-	-	-	-
		23	29	-	20	-	-	-	8.8	-	6.1	-	-	-
		27	27	-	-	-	-	-	8.2	-	-	-	-	-
		28	23	-	-	-	-	-	7	-	-	-	-	-
		29	23	28	-	-	-	-	7	8.5	-	-	-	-
		30	23	47	-	-	-	-	7	14.3	-	-	-	-
		32	29	-	-	-	-	-	8.8	-	-	-	-	-
		33	26	-	-	-	-	-	7.9	-	-	-	-	-
		34	18	59	-	15	-	-	5.5	18	-	4.6	-	-
		35	18	52	-	-	-	-	5.5	15.8	-	-	-	-
9	10	1	19	32	-	-	-	-	5.8	9.8	-	-	-	-
		2	14	-	-	-	-	-	4.3	-	-	-	-	-
		11	-	11	-	-	-	-	-	3.4	-	-	-	-
		12	20	-	-	-	-	-	6.1	-	-	-	-	-
		13	8	-	-	-	-	-	2.4	-	-	-	-	-
		25	15	-	-	-	-	-	4.6	-	-	-	-	-
		28	7	160	-	-	-	-	2.1	48.8	-	-	-	-
		29	42	-	-	-	-	-	12.8	-	-	-	-	-
		35	10	-	-	-	-	-	3	-	-	-	-	-
9	11	31	6	-	-	-	-	-	1.8	-	-	-	-	-
9	13	4	-	60	-	-	-	-	-	18.3	-	-	-	-
		20	-	-	-	33	-	-	-	-	-	10.1	-	-
		27	-	46	-	-	-	-	-	14	-	-	-	-
		29	-	21	-	-	-	-	-	6.4	-	-	-	-
		30	-	24	-	-	-	-	-	7.3	-	-	-	-
10	8	29	29	-	-	-	-	-	8.8	-	-	-	-	-

Table 13 (continued)

Twp	Rge	Sec	Average Depth to Water by Well Depth (In Feet) 0-99	100-199	200-299	300-399	400-499	>500	(In Meters) 0-30	30-61	61-91	91-121	121-152	>152
10	9	2	20	-	-	-	-	-	6.1	-	-	-	-	-
		7	15	-	-	-	-	-	4.6	-	-	-	-	-
		11	-	100	-	-	-	-	-	30.5	-	-	-	-
		17	16	16	140	27	-	-	4.9	4.9	42.7	8.2	-	-
		18	11	-	-	-	-	-	3.4	-	-	-	-	-
		19	12	43	-	20	-	-	3.7	13.1	-	6.1	-	-
		21	12	-	-	-	-	-	3.7	-	-	-	-	-
		22	10	24	-	-	-	-	3	7.3	-	-	-	-
		23	30	33	23	37	-	-	9.1	10.1	7	11.3	-	-
		25	12	49	-	25	-	10	3.7	14.9	-	7.6	-	3
		26	8	8	9	-	-	-	2.4	2.4	2.7	-	-	-
		27	13	34	23	9	-	-	4	10.4	7	2.7	-	-
		28	10	9	-	-	-	-	3	2.7	-	-	-	-
		29	17	21	-	-	-	-	5.2	6.4	-	-	-	-
		32	5	18	-	-	-	-	1.5	5.5	-	-	-	-
		33	7	7	-	-	-	-	2.1	2.1	-	-	-	-
		34	11	9	-	-	-	-	3.4	2.7	-	-	-	-
		35	15	19	-	-	5	-	4.6	5.8	-	-	1.5	-
		36	22	27	16	35	33	-	6.7	8.2	4.9	10.7	10.1	-
10	10	1	6	-	-	-	-	-	1.8	-	-	-	-	-
		2	-	31	-	-	-	-	-	9.4	-	-	-	-
		9	30	25	-	-	-	-	9.1	7.6	-	-	-	-
		11	9	-	-	-	-	-	2.7	-	-	-	-	-
		12	-	12	-	-	-	-	-	3.7	-	-	-	-
		13	18	29	10	-	-	-	5.5	8.8	3	-	-	-
		14	-	40	-	145	-	-	-	12.2	-	44.2	-	-
		15	12	60	-	-	-	-	3.7	18.3	-	-	-	-
		16	16	-	-	-	-	-	4.9	-	-	-	-	-
		17	14	35	-	-	-	-	4.3	10.7	-	-	-	-
		18	12	-	-	-	-	-	3.7	-	-	-	-	-
		20	10	-	-	-	-	-	3	-	-	-	-	-
		21	19	30	-	-	-	-	5.8	9.1	-	-	-	-
		22	12	90	-	-	-	-	3.7	27.4	-	-	-	-
		23	13	17	-	-	-	-	4	5.2	-	-	-	-
		24	-	45	-	-	-	-	-	13.7	-	-	-	-
		26	13	-	-	-	-	-	4	-	-	-	-	-
		27	16	30	40	-	-	-	4.9	9.1	12.2	-	-	-
		28	10	-	-	-	-	-	3	-	-	-	-	-
		34	13	-	-	-	-	-	4	-	-	-	-	-
		35	23	-	-	-	-	-	7	-	-	-	-	-
10	11	12	27	-	-	-	-	-	8.2	-	-	-	-	-
		13	11	-	-	-	-	-	3.4	-	-	-	-	-
10	13	17	-	16	-	-	-	-	-	4.9	-	-	-	-
		25	2	-	-	-	-	-	.6	-	-	-	-	-
10	14	10	-	-	40	-	-	-	-	-	12.2	-	-	-
		12	25	35	-	-	-	-	7.6	10.7	-	-	-	-
		13	-	40	-	-	-	-	-	12.2	-	-	-	-
		14	-	35	-	-	-	-	-	10.7	-	-	-	-
		16	-	8	-	-	-	-	-	2.4	-	-	-	-
		28	29	-	-	-	-	-	8.8	-	-	-	-	-
11	9	11	-	-	99	-	-	-	-	-	30.2	-	-	-
11	10	5	15	-	-	-	-	-	4.6	-	-	-	-	-
		6	18	30	10	-	-	-	5.5	9.1	3	-	-	-
		7	15	11	-	-	-	-	4.6	3.4	-	-	-	-
		8	20	45	-	-	-	-	6.1	13.7	-	-	-	-
		17	17	45	-	-	-	-	5.2	13.7	-	-	-	-
		18	15	-	-	-	-	-	4.6	-	-	-	-	-
		21	10	-	-	-	-	-	3	-	-	-	-	-
		27	6	-	-	-	170	200	1.8	-	-	-	51.8	61
		28	8	-	-	100	-	-	2.4	-	-	30.5	-	-
		29	13	-	-	-	-	15	4	-	-	-	-	4.6
		30	8	-	-	-	-	-	2.4	-	-	-	-	-
		32	50	-	-	-	80	-	15.2	-	-	-	24.4	-
		33	9	14	-	-	-	-	2.7	4.3	-	-	-	-
		34	13	-	-	-	-	-	4	-	-	-	-	-
		35	7	-	-	-	-	-	2.1	-	-	-	-	-
11	11	1	12	-	-	-	-	-	3.7	-	-	-	-	-
		13	46	-	-	-	-	-	14	-	-	-	-	-
12	10	31	8	-	-	-	-	-	2.4	-	-	-	-	-
		33	-	-	40	-	-	-	-	-	12.2	-	-	-
		34	-	-	60	-	-	-	-	-	18.3	-	-	-

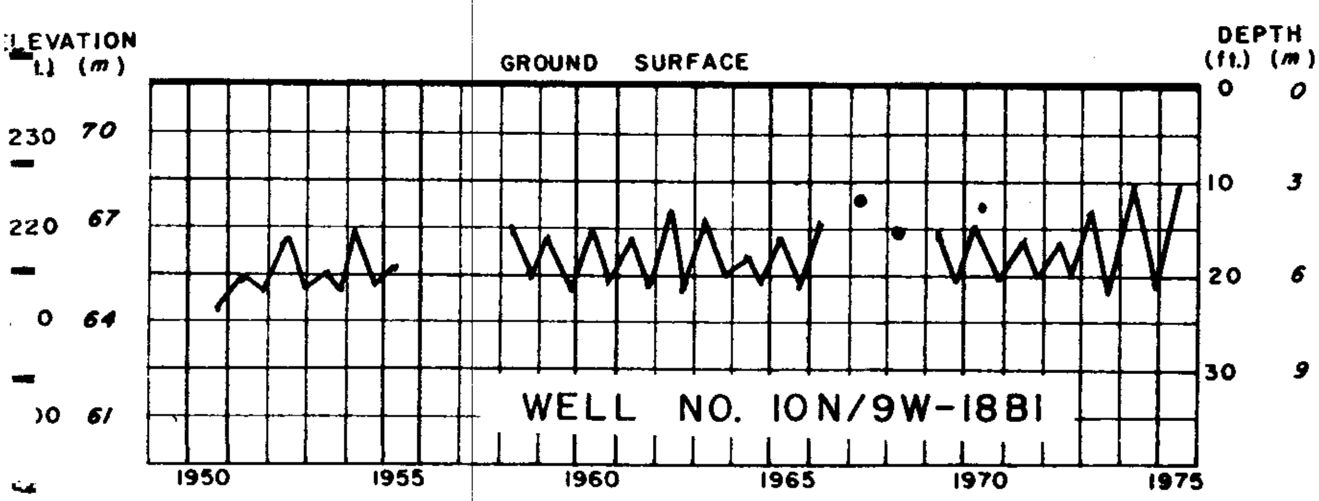


Well depth: 110 ft. (33 m)
Water-bearing materials: Alluvium and Glen Ellen Formation
Location: Santa Rosa Plain near Windsor

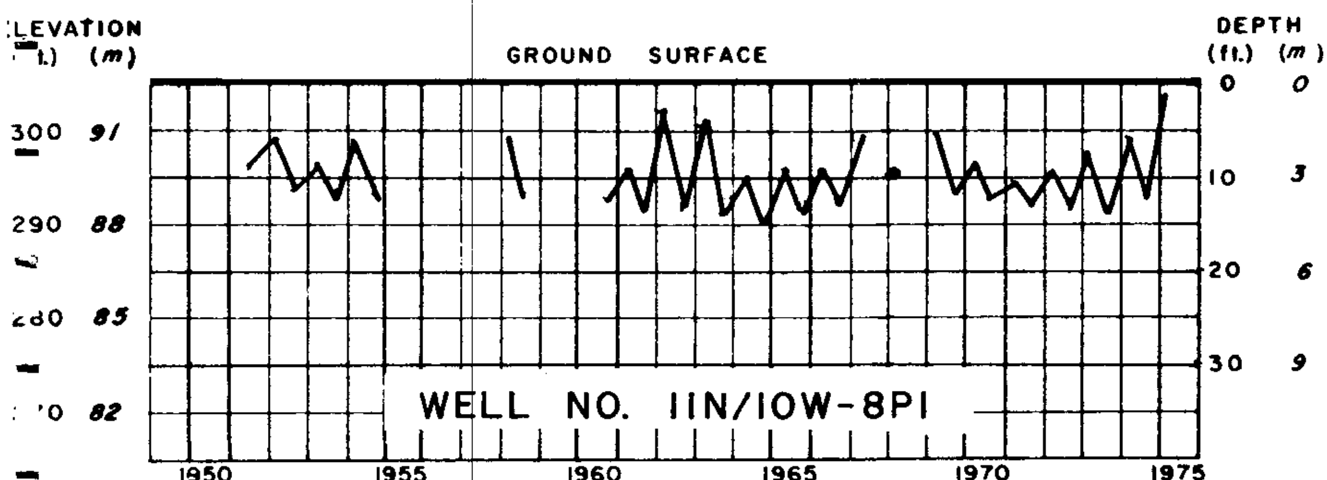


Well depth: 53 ft. (16 m)
Water-bearing materials: Stream channel deposits
Location: Santa Rosa Plain near Healdsburg

SELECTED HYDROGRAPHS

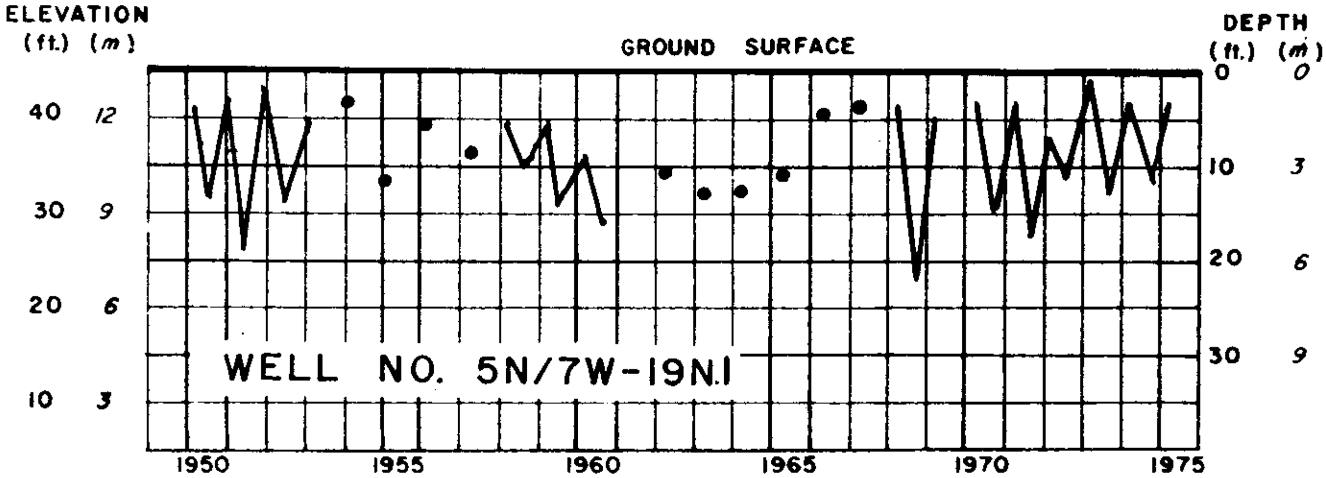


Well depth: 180 ft. (55 m)
Water-bearing materials: Alluvium
Location: Alexander Valley near Geyserville

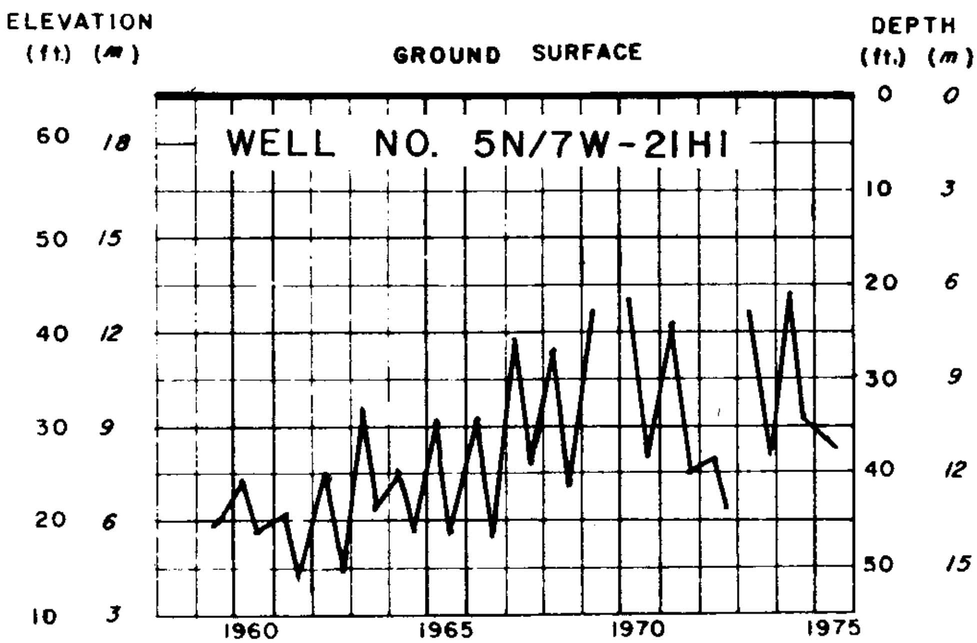


Well depth: 28 ft. (9 m)
Water-bearing materials: Alluvium
Location: Cloverdale Valley east of Cloverdale

SONOMA COUNTY

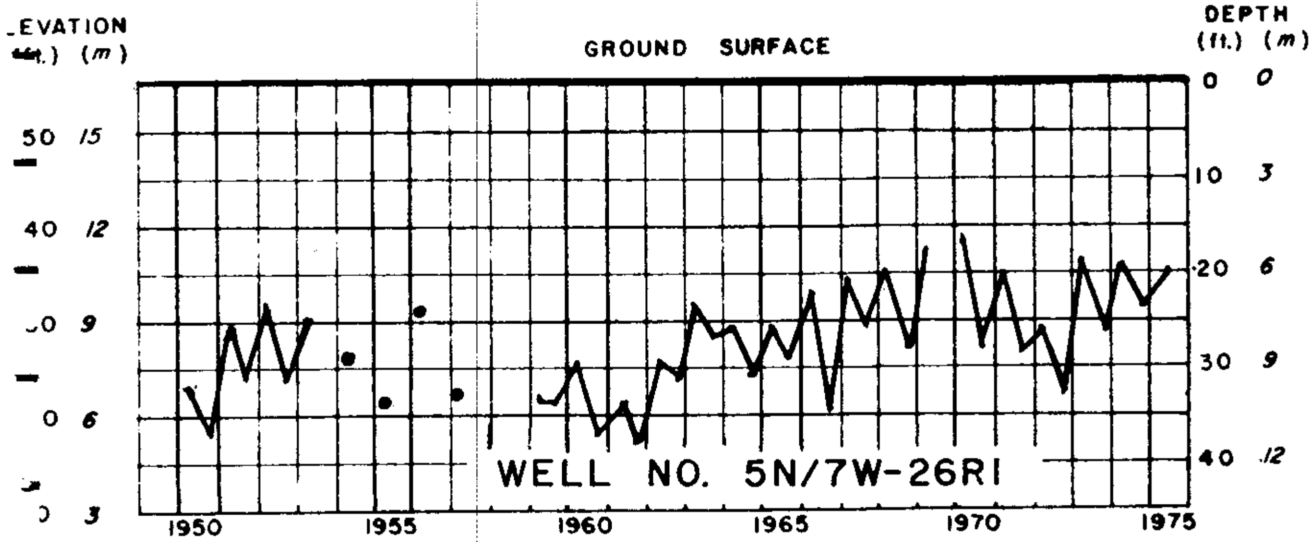


Well depth: 180 ft. (55 m)
Water-bearing materials: Merced Formation
Location: Petaluma Valley northwest of Petaluma

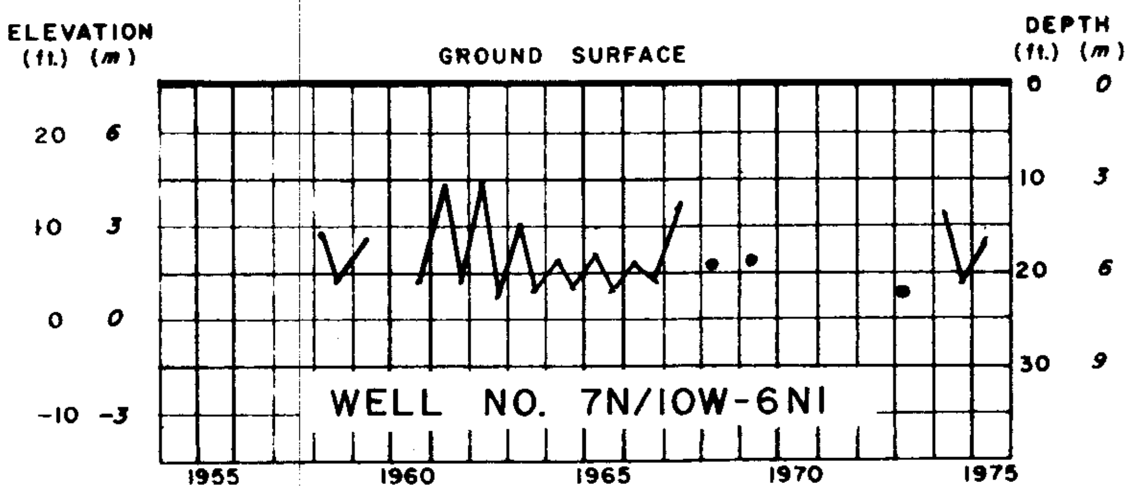


Well depth: 50 ft. (15 m)
Water-bearing materials: Alluvium
Location: Petaluma Valley north of Petaluma

SELECTED HYDROGRAPHS

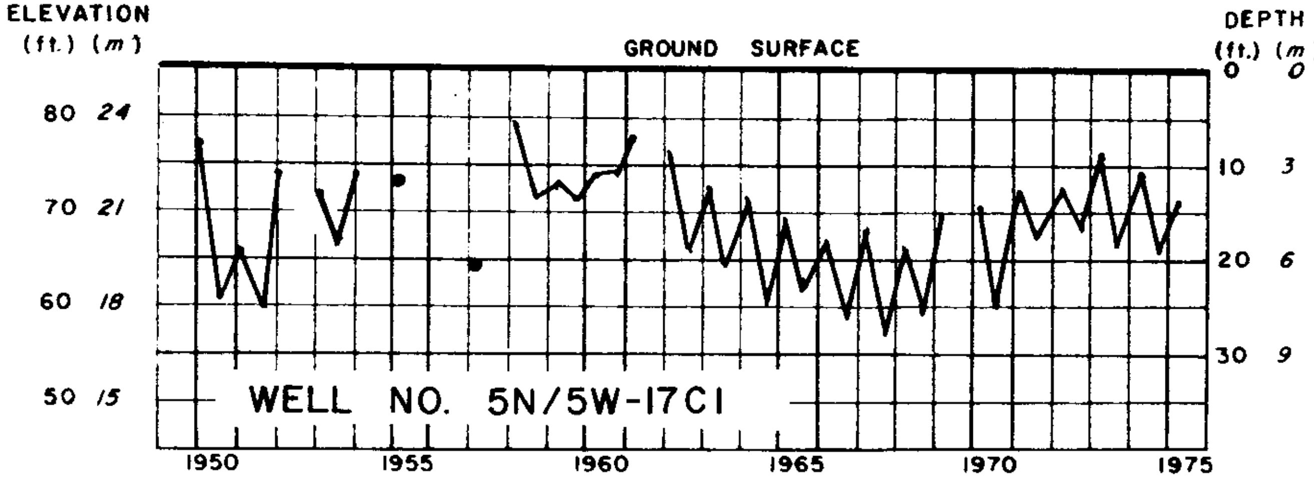


Well depth: 428 ft. (130 m)
Water-bearing materials: Petaluma Formation
Location: Petaluma Valley east of Petaluma

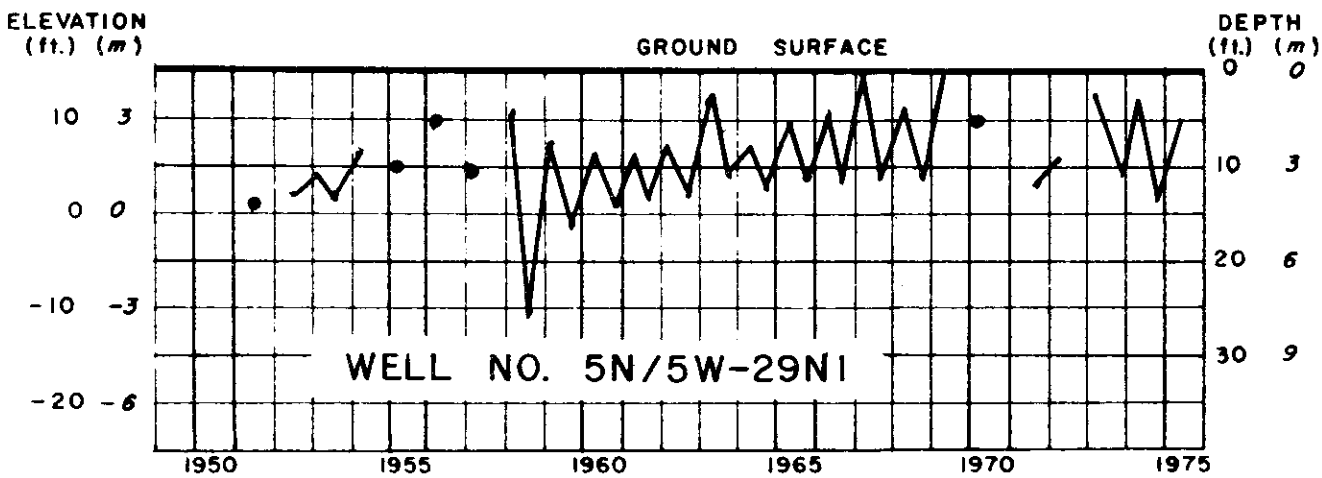


Well depth: 120 ft. (39 m)
Water-bearing materials: Stream channel deposits
Location: Lower Russian River Valley near Monte Rio

SONOMA COUNTY

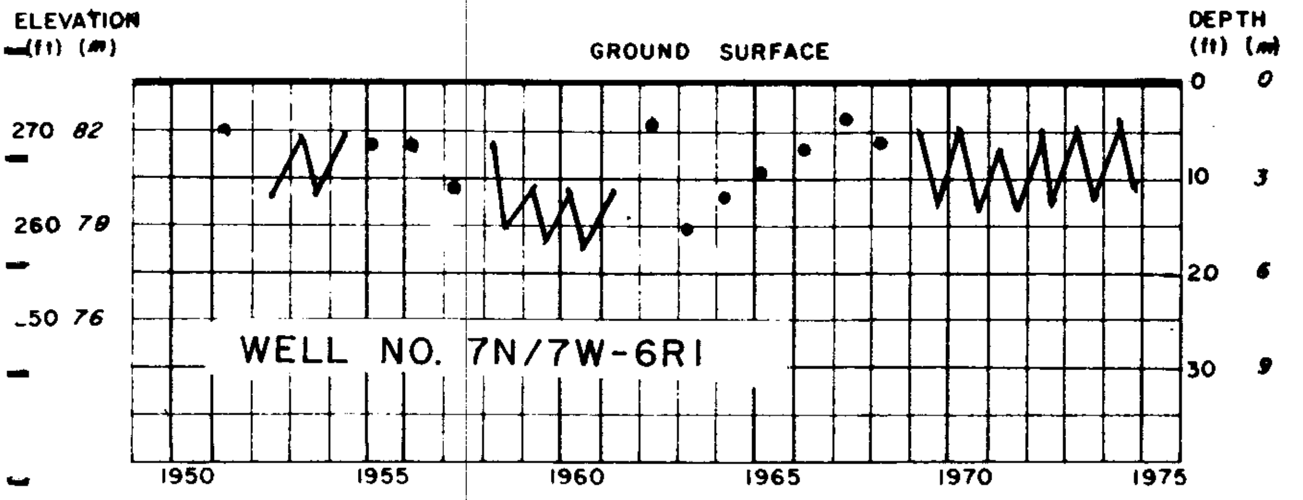


Well depth: 70 ft. (21 m)
Water-bearing materials: Alluvium
Location: Sonoma Valley east of Sonoma

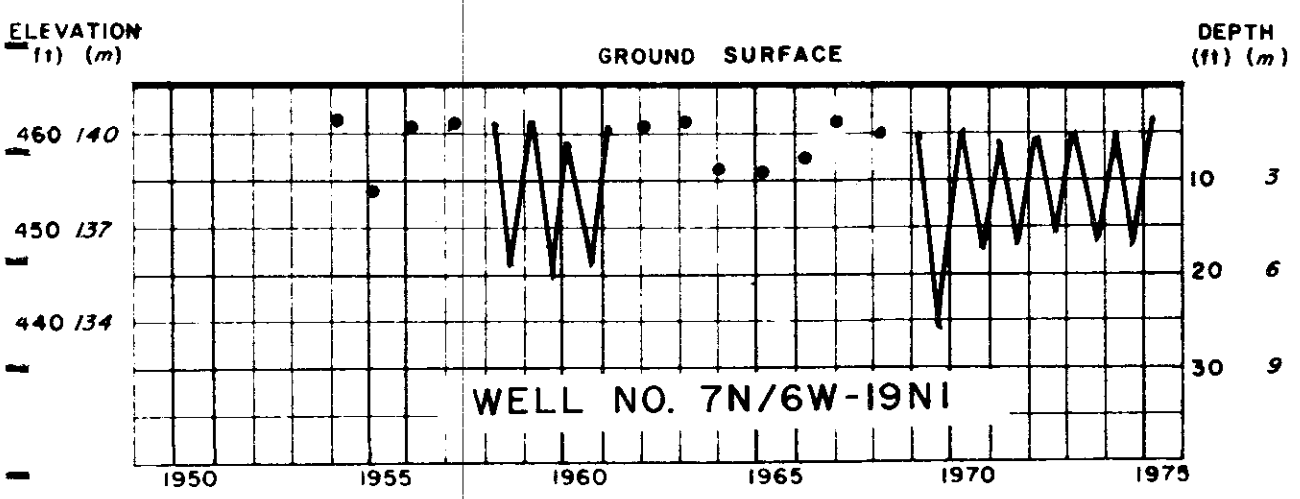


Well depth: 100 ft. (30 m)
Water-bearing Materials: Alluvium
Location: Sonoma Valley near Schellville

SELECTED HYDROGRAPHS



Well depth: 133 ft. (40 m)
Water-bearing materials: Alluvium and Glen Ellen Formation
Location: Rincon Valley northeast of Santa Rosa



Well depth: 149 ft. (45 m)
Water-bearing materials: Alluvium and Glen Ellen Formation
Location: Kenwood Valley northwest of Kenwood

SONOMA COUNTY

Well No. 6N/8W-15J3 taps a mixture of alluvium and Glen Ellen Formation sediments. Since the spring of 1950, water levels have declined about 21 feet (7 m), suggesting that increased pumping in this aquifer system may accellerate ground water declines. In the Petaluma Valley, water levels in Well No. 5N/7W-26R1, which taps the Petaluma Formation, have recovered about 5 feet (1.5 m) during its 25-year record. The hydrograph infers that additional pumpage may be supported by this formation without significant declines in water levels.

Natural Recharge Areas

The natural areas of recharge to the ground water body in Sonoma County are restricted to only a few geologic units. Natural recharge may take place along much of the stream channel deposits, alluvial fan deposits, selected areas of alluvium, and much of the surficial area of the Merced Formation (see Plate 1). According to Cardwell (1958), where these areas are of gentle slope and runoff is not severe, a significant amount of water can infiltrate and enter the ground water body. According to data from the U. S. Department of Agriculture (1950), the Merced Formation in the area southwest of Sebastopol has an infiltration rate of 0.7 acre-feet per day per acre (2,163 cubic meters per day per hectare). On the basis of this figure and assuming that there are 30,000 acres (12,120 hectares) of exposed Merced sediments, the total recharge capability of the outcrop area of the Merced Formation is about 21,000 acre-feet per day (about 26 hm^3 per day).

Cardwell (1958) pointed out that the potential recharge capability of an area can be materially reduced when water levels are at or near the ground surface. This condition frequently is the case in many low-lying areas where water levels are high and water cannot infiltrate even though soils may be permeable. Cardwell also noted that many of the streams in central Sonoma County appear to be gaining streams. That is, ground water discharges into the stream and helps to maintain streamflow. In a few cases, such as in Alexander Valley, the Russian River is a gaining stream during much of the year. In the fall, however, when water levels are depressed, the Russian River is a losing stream because it helps recharge the ground water body. Figure 15 shows the natural recharge areas of Sonoma County.

Present Ground Water Development

In 1951, a section was added to the California Water Code requiring water well drillers to file Water Well Drillers Reports with the Department of Water Resources. Since that time, many thousands of well logs have been placed on file for Sonoma County. During the present investigation, a computerized listing of all well logs was made for the county. The tabulation, which identifies 10,199 water wells as of July 1, 1973, provides the name of the owner at the time the well was drilled, the well location number, and pertinent data such as depth, year drilled, identification of well driller, etc. From this tabulation it has been possible to determine for the first time the magnitude of water well development in the various ground water basins and contiguous areas in Sonoma County.

Well Density

Figure 16 shows the relative density of water wells in Sonoma County. Well densities range from less than five wells per section, in areas of nonwater-bearing rock, to over 100 wells per section in five highly urbanized sections. The section of highest density of water wells is located southwest of Sebastopol, in Section 12, Township 6 North, Range 9 West. This section contains 180 identified water wells.

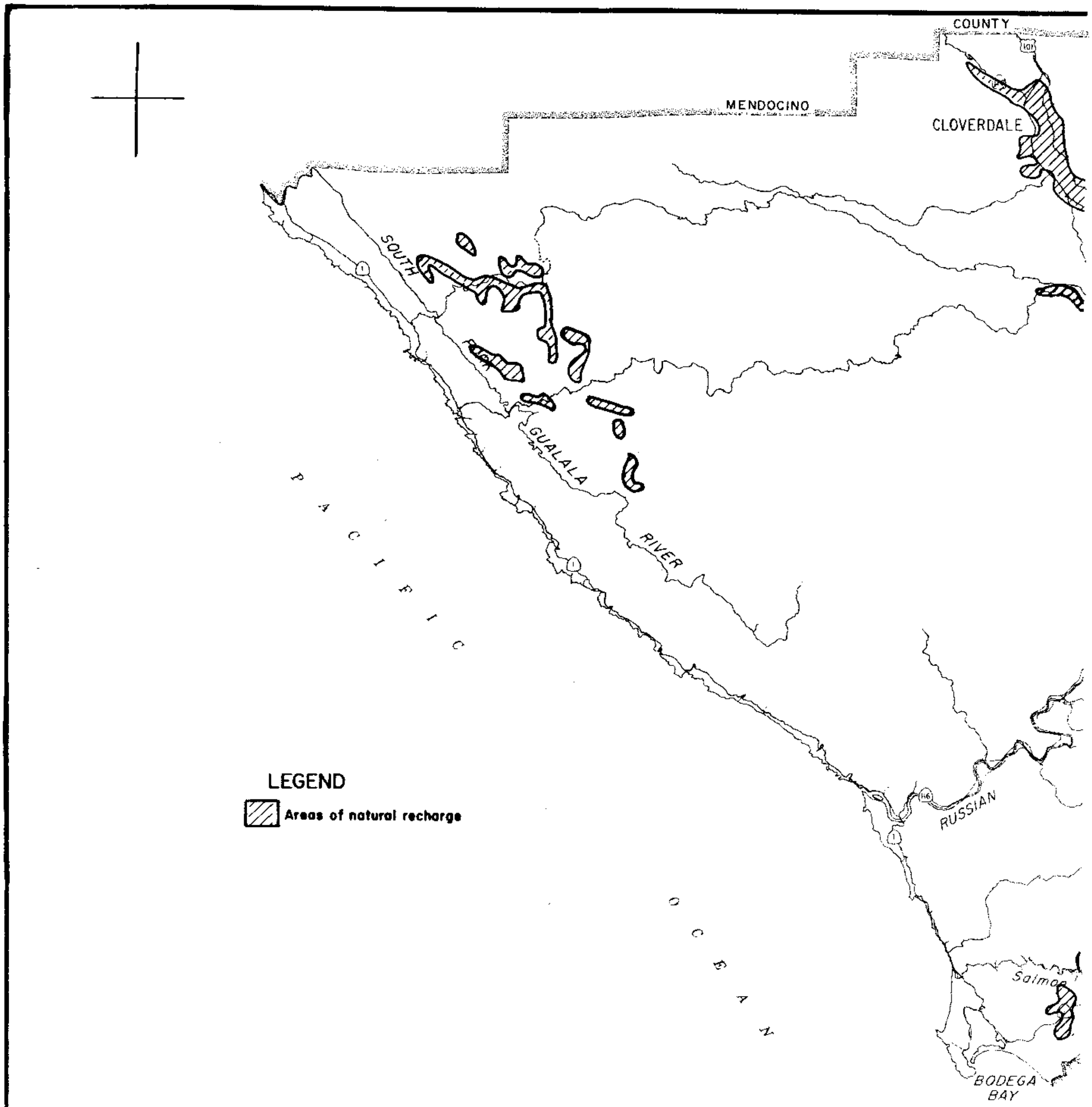
Sanitary Seals

Most wells constructed in Sonoma County since 1965 have a sanitary seal which extends to a depth of from 20 to 50 feet (6 to 15 meters) below ground; in contrast, many older wells do not have sanitary seals. Ritchie (1968) discusses methods of sealing the upper portion of water wells and points out the importance of sanitary seals with regard to the preservation of ground water quality.

A comparison of the density of water wells shown on Figure 16, with the percentage of wells with sanitary seals shown on Figure 17, shows that some areas have a high degree of protection of the underlying ground water and others do not. For example, there are 129 wells in Section 18, Township 6 North, Range 8 West, located southeast of Sebastopol. In this section, 71 (55 percent) of the wells have a sanitary seal. In contrast, there are 108 wells in Section 2, Township 6 North, Range 8 West; here only 33 wells (30.5 percent) have sanitary seals.

Well Yield

Reliable yield data are available from 256 wells, or about 2.5 percent of the total number of wells in the county. These data are provided from wells from which extended pump tests were run; bailer tests are not included due to uncertainties inherent in that type of test. The data indicate that well yields range



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

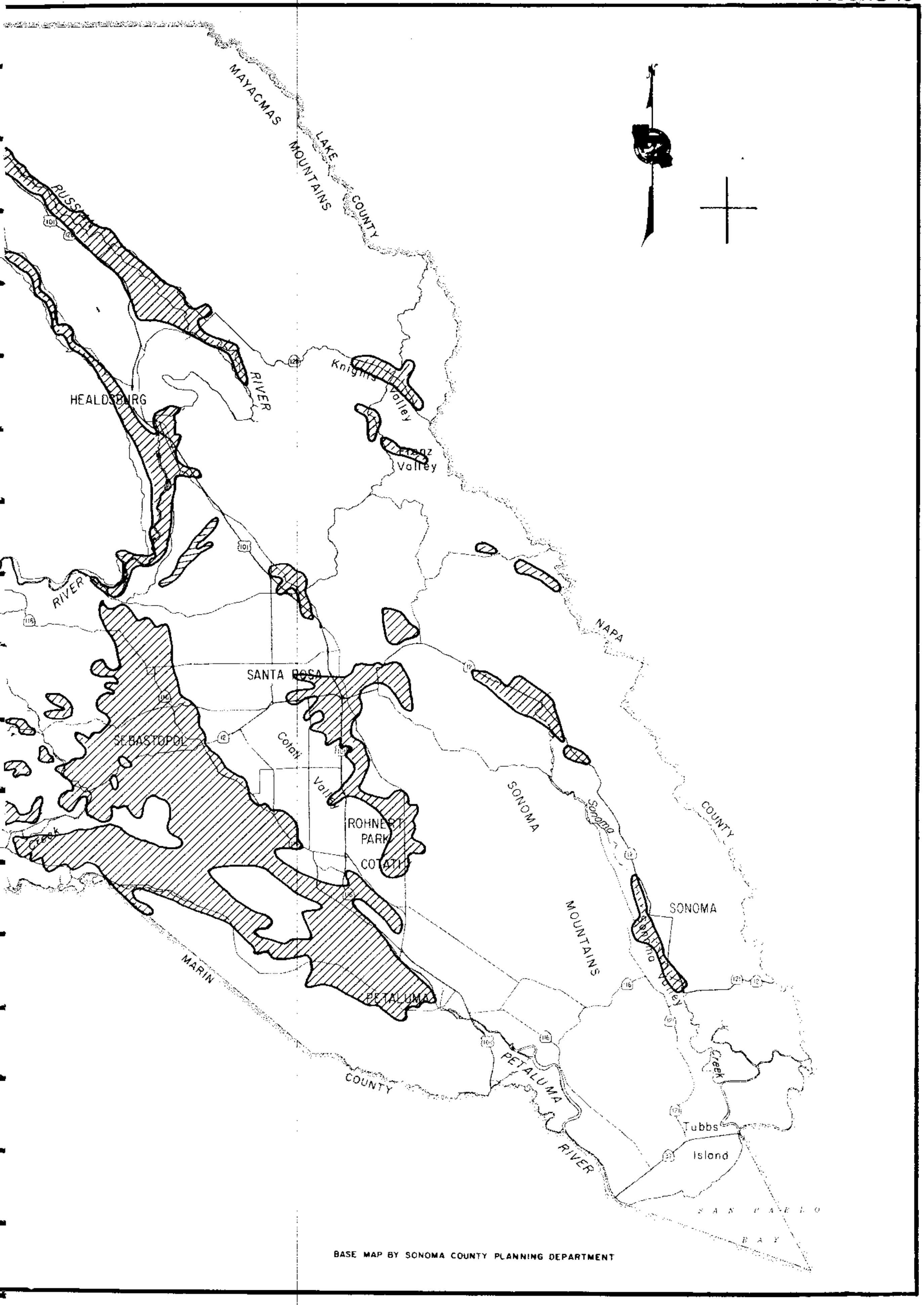
SONOMA COUNTY
GROUND WATER RESOURCES INVESTIGATION

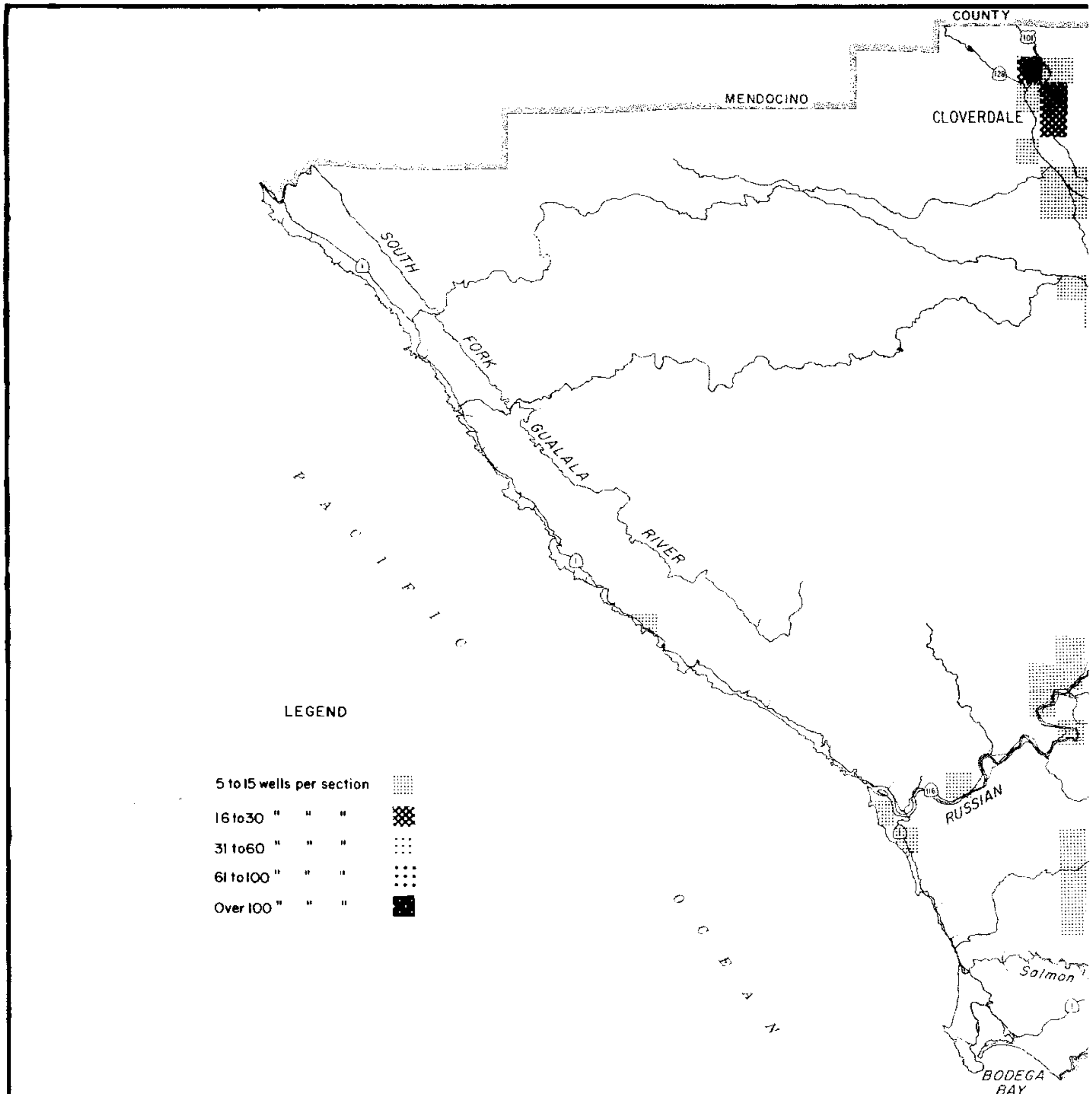
NATURAL RECHARGE AREAS

1975

SCALE OF MILES

0 1 2 3 4 5 6 7 8 9 10


MAYACMAS
MOUNTAINS
LAKE
COUNTY
RUSSIAN
RIVER
HEALDSBURG
Knights Valley
Franz Valley
RIVER
NAPA
COUNTY
SANTA ROSA
SEBASTOPOL
Cotati
Valley
ROHNERT PARK
COTATI
SONOMA
MOUNTAINS
Sonoma
SONOMA
Sonoma Valley
Creek
MARIN
COUNTY
PETALUMA
PETALUMA
RIVER
Creek
Tubbs
Island
SAN PABLO
BAY
BASE MAP BY SONOMA COUNTY PLANNING DEPARTMENT



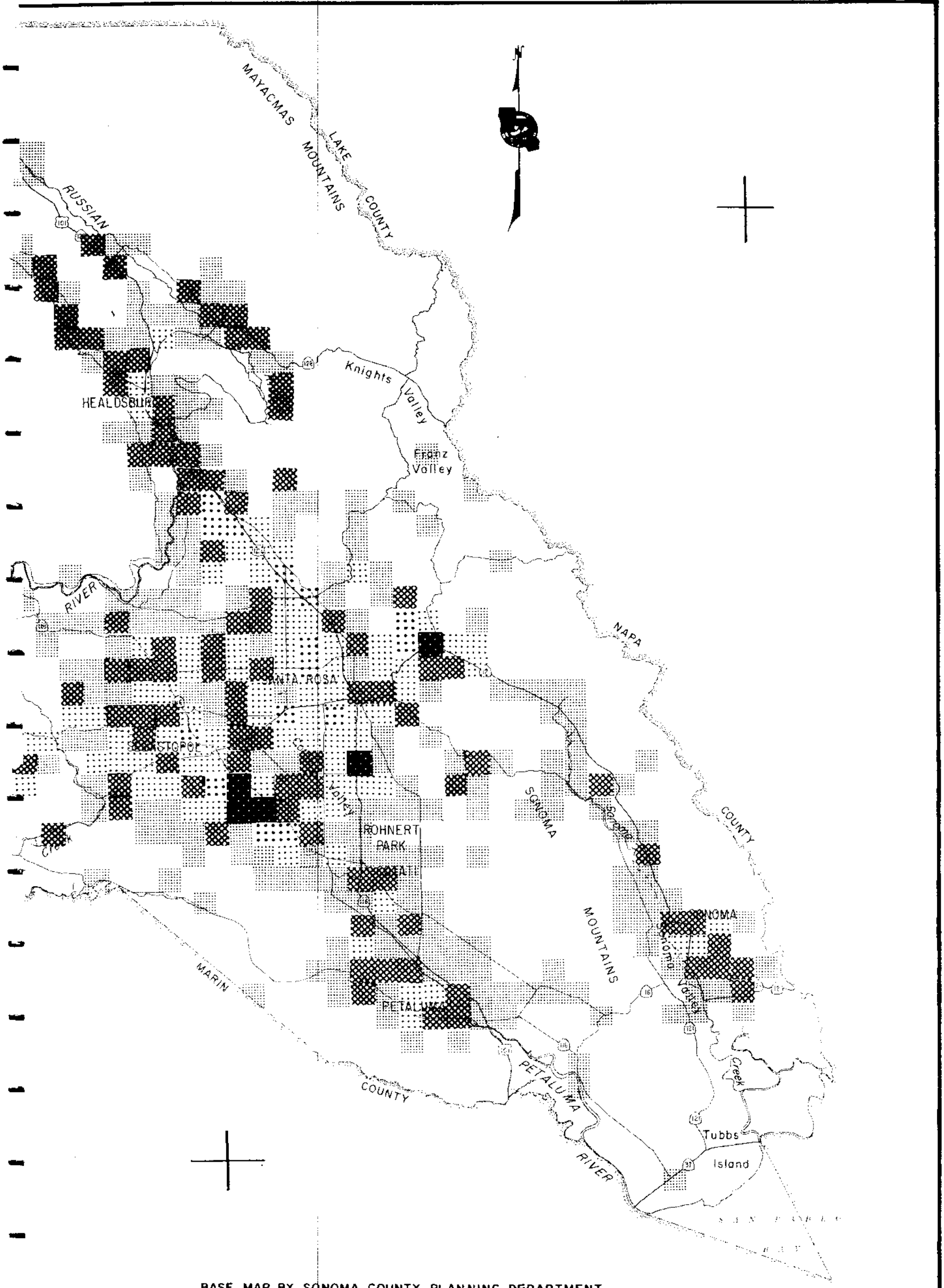
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY
GROUND WATER RESOURCES INVESTIGATION

DENSITY OF WATER WELLS

1975

SCALE OF MILES


MAYACMAS
MOUNTAINS
LAKE
COUNTY
RUSSIAN
RIVER
Knights
Valley
Franz
Valley
HEALDSBURG
NAPA
COUNTY
SANTA ROSA
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Sonoma
ROHNERT
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MARIN
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PETALUMA
PETALUMA
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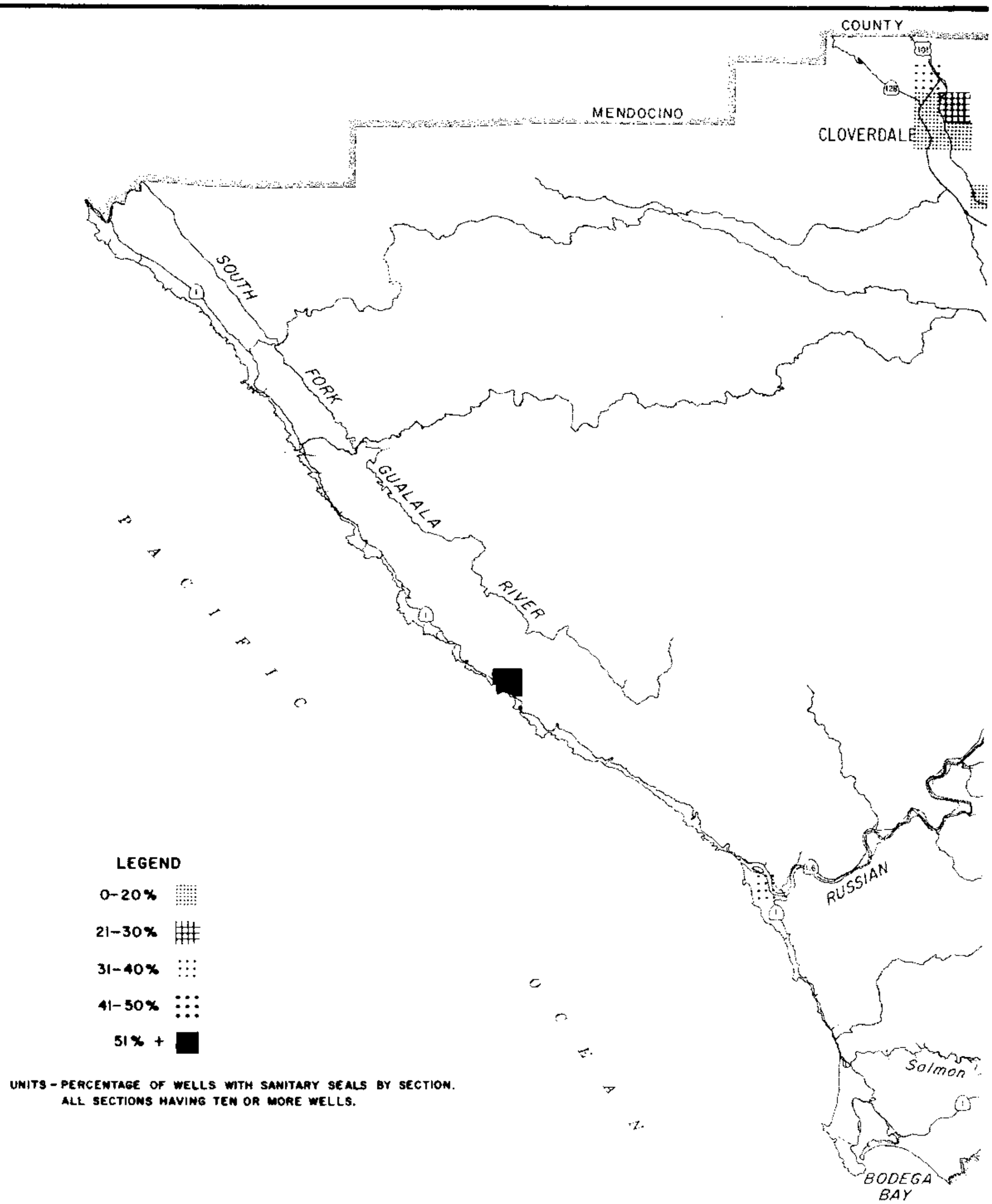
Tubbs
Island
SAN PABLO
BAY
BASE MAP BY SONOMA COUNTY PLANNING DEPARTMENT



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY
GROUND WATER RESOURCES INVESTIGATION

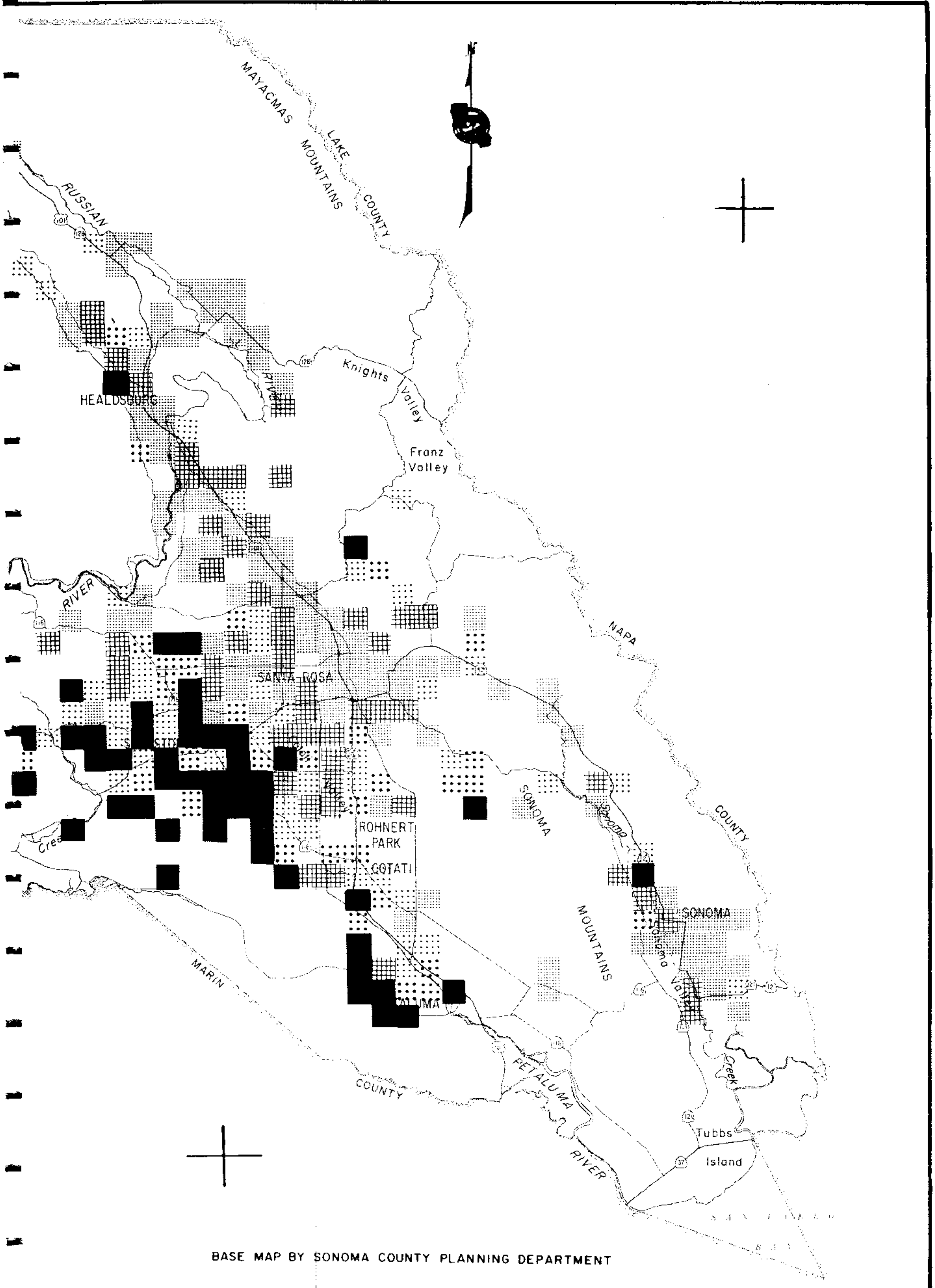
PERCENTAGE OF WELLS WITH SANITARY SEALS

1975

SCALE OF MILES

0 1 2 3 4 5 6 7 8 9 10

FIGURE 17



BASE MAP BY SONOMA COUNTY PLANNING DEPARTMENT

from greater than 200 gpm per foot (2,479 l/m per meter) of drawdown for a few wells located near the Russian River, to less than 5 gpm per foot (61.9 l/m per meter) of drawdown for many wells located throughout the county. Figure 18 presents information on the specific capacity of wells in the county.

Springs

Springs are an important source of ground water in the mountainous areas of Sonoma County. Of the hundreds of springs present, 413 have been identified on 7½-minute topographic maps; the locations of these identified springs are shown on Figure 19. Of these springs, 22 are of sufficient importance to be named on maps.

There are two basic types of springs in Sonoma County. One is the bedrock or natural water table spring. This type includes most of the unnamed springs on Figure 19, as well as ten of the named springs. Springs of this type issue from fractures and joints in the rock and are proof that ground water is present.

The other type of spring yields mineralized and/or thermal waters. Shown on Figure 19 are three areas of thermal springs, ranging from warm springs at Mark West and Morton's Springs to the hot springs at The Geysers, Little Geysers, and Skaggs Springs. Mineralized cold springs include those at Alder Glen and Kawana Springs. Although not actually thermal springs, there also are three areas of thermal wells in Sonoma Valley which are shown on Figure 19; these are Agua Caliente, Fetters Springs, and Boyes Springs. Development of these latter three hot spring areas was the result of natural thermal springs which once issued from the bed of Sonoma Creek. Thermal wells were drilled in this area as early as 1890, when the thermal water was used for mineral baths.

Waring (1915) identified 21 springs in Sonoma County and included a description of their facilities and uses (resorts, bathing pools, medicinal purposes, etc.). Seven of the 21 springs could not be located during the present investigation because of inadequate descriptions. The unlocated springs included an undeveloped carbonate spring on Little Sulfur Creek, three undeveloped sulfur springs (in Franz Valley, on Sulfur Creek, and on Little Sulfur Creek), two developed sulfur springs (O'Donnel's Springs near Glen Ellen and Wall Springs south of Healdsburg), and a hot spring (Ohm's Spring, a thermal well resort south of Boyes Springs). Lytton Springs, a sodium carbonate spring north of Healdsburg, also was described by Waring, but this spring is no longer in existence as it was covered over in 1927. Hoods Hot Springs, formerly on Dry Creek near the Mendocino County line, no longer exists according to recent investigations done by the U. S. Corps of Engineers in connection with Warm Springs Dam and Reservoir.

Table 14

DESCRIPTION OF SPRINGS IN SONOMA COUNTY

Name of Spring	Location	Elevation (feet)	(meters)	Discharge (gpm)	(l/mn)	Water Type	Rock Type	Remarks
Agua Caliente	Sonoma Valley	140	43	--	--	Sodium chloride	Sonoma Volcanics	Several thermal wells drilled to depths of 200 to 400 feet (*61 - 122 meters*) serve Agua Caliente plunge.
Alderglen Spring	Northwest of Cloverdale	500	152	0.5	1.9	Calcium bicarbonate	Jura-Cretaceous	Abandoned resort.
Armstrong Spring	Armstrong Redwoods State Park	200	61	<0.1	<0.4	Sodium and calcium bicarbonate	Jura-Cretaceous	Unused.
Baumert Spring	Camp Meeker	750	229	--	--	--	Jura-Cretaceous	
Bedrock Spring	Northwest of Bodega	450	137	--	--	--	Merced Formation	
Big Spring	Northeast of Rincon Valley	1,640	500	1	3.8	Calcium bicarbonate	Landslide and Sonoma Volcanics	Forms creek from which domestic use is made 1 to 3 miles downstream.
Boyes Springs	Sonoma Valley	150	46	--	--	Sodium chloride	Sonoma Volcanics	Several thermal wells drilled to depths of about 200 feet (*61 meters*) serve Mission Inn Resort.
Buckeye Spring	Mayacmas Mountains	2,200	671	5	18.9	Calcium and magnesium bicarbonate	Landslide in Jura-Cretaceous	Unused.
Buzzard Spring	Southwest of Healdsburg	750	229	--	--	--	Jura-Cretaceous	
Cold Springs	Mayacmas Mountains	2,300	701	--	--	--	Jura-Cretaceous	Piped to house for domestic use.
Eldridge Spring	Sonoma Valley	240	73	10	37.9	Sodium bicarbonate	Glen Ellen Formation	Warm spring. Unused.
Fern Spring	South of Monte Rio	1,325	404	--	--	--	Jura-Cretaceous	
Fetters Springs	Sonoma Valley	130	40	--	--	Sodium chloride	Sonoma Volcanics	Several thermal wells drilled to depths of 200 to 400 feet (*61 - 122 meters*) serve Fetters Springs Resort.
Gravelly Spring	North of Cazadero	1,050	320	--	--	--	Jura-Cretaceous	
Kawana Spring	Southeast of Santa Rosa	170	52	4	15.1	Sodium bicarbonate	Sonoma Volcanics	Domestic use. Formerly called Taylor Springs.
Keiser Spring	Northwest of Glen Ellen	420	128	20	75.7	Sodium and magnesium bicarbonate	Sonoma Volcanics	Warm spring. Used for domestic, irrigation, and stock watering. Formerly called McEwan Ranch Spring.
Little Geysers	Mayacmas Mountains	2,400	732	--	--	--	Jura-Cretaceous	Hot springs. Significant geothermal resource area.
Mark West Spring	East of Windsor	430	131	0.2	0.8	Calcium and magnesium bicarbonate	Sonoma Volcanics	Warm spring. Unused.
Mineral Spring	North of Cazadero	850	259	0.3	1.1	Calcium bicarbonate	Jura-Cretaceous	Domestic use.
Morton's Warm Spring	Northwest of Glen Ellen	350	107	20	75.7	Sodium bicarbonate	Sonoma Volcanics	Warm springs; formerly called Los Guilicos Springs. Used for swimming pool supply at Morton's Warm Springs Resort.
Mud Spring	Northwest of Bodega	475	148	--	--	--	Merced Formation	
Nuns Spring	East of Kenwood	1,300	396	1	3.8	Sodium bicarbonate	Sonoma Volcanics and Tertiary Marine Sediments	Unused.
Pedotti Spring	Southeast of Fort Ross	400	122	>0.5	>1.9	Calcium and magnesium bicarbonate	Landslide in Jura-Cretaceous	Domestic and stock use.
Redwood Lake Spring	Armstrong Redwoods State Park	1,350	411	--	--	Calcium and sodium bicarbonate	Jura-Cretaceous	Unused.
Russian Trough Spring	Northeast of Fort Ross	1,400	427	--	--	--	Jura-Cretaceous	
Skaggs Springs	Northwest of Healdsburg	320	98	4	15.1	Sodium bicarbonate	Jura-Cretaceous	Unused hot spring. In reservoir area of Lake Sonoma.
The Geysers	Mayacmas Mountains	1,400-1,800	427-549	--	--	Magnesium bicarbonate, magnesium and ammonium sulfate	Jura-Cretaceous	Large group of hot springs; most are unused. Significant geothermal resource area.
Unnamed Spring (#1)	North of Cazadero at The Cedars	899	274	--	--	Calcium hydroxide	Serpentine	Unused. West of Austin Creek.
Unnamed Spring (#2)	North of Cazadero at The Cedars	1,000	305	--	--	Magnesium bicarbonate	Serpentine	Unused. In bed of Austin Creek.
Unnamed Spring (#3)	Mayacmas Mountains	2,300	701	>6	>22.7	Calcium and magnesium bicarbonate	Jura-Cretaceous	Public use in roadside trough. Located between Buckeye and Cold Springs.
Unnamed Spring (#4)	Mayacmas Mountains	1,360	415	<0.5	<1.9	Calcium bicarbonate	Sonoma Volcanics	Domestic use. Located 2,000 feet west of Big Spring.

Table

MINERAL ANALYSES OF

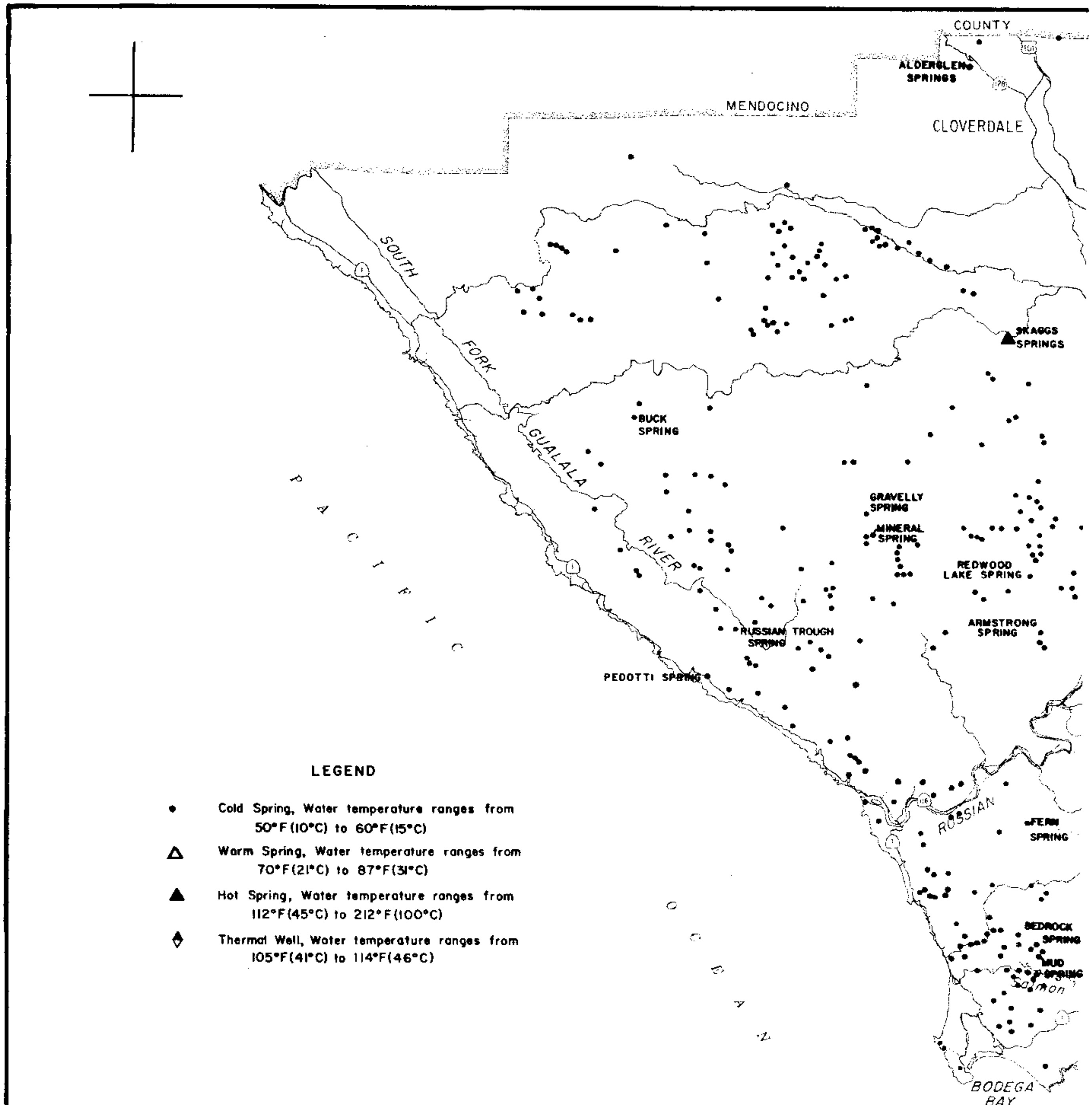
Name	Data Source a/	Temperature °F	Temperature °C	Specific Conductance (micromhos)	Total Hardness (mg/l)	Total Dissolved Solids (mg/l)	Ca^{++}	Mg^{+}
Agua Caliente	2	114	46	--	--	--	1.0	10
Alderglen Spring	1	58	14	1,230	445	685	92	52
Armstrong Spring	3	--	--	232	84	151	22	7
Big Spring	1	62	18	134	44	112	9.7	2.3
Boyes Spring	1	105	41	1,310	18	--	7.7	0
Buckeye Spring	1	58	14	248	112	157	22	14
Eldridge Spring	3	70	21	521	88	370	19	9.8
Kawana Spring	3	53	12	282	28	184	7.2	2.4
Keiser Spring	3	73	23	311	110	260	21	14
Mark West Spring	3	87	31	399	156	327	31	19
Mineral Spring	1	58	14	389	138	214	45	6.1
Morton's Warm Spring	3	87	31	684	80	491	20	7.2
Nuns Spring	1	68	20	84	9	80	2.2	0.8
Pedotti Spring	3	--	--	452	202	273	46	21
Redwood Lake Spring	3	56	13	153	54	116	13	5.3
Skaggs Spring	3	132	56	3,440	56	2,500	14	4.5
The Geysers								
Spring "13A" c/	3	113	45	15,800	1,970	10,600	42	453
Spring "13H"	3	112	44	599	318	431	32	58
Spring "13X"	3	128	54	670	327	466	32	60
Devils Kitchen	3	212	100	--	--	7,770	47	281
Unnamed Spring (#1) d/	4	--	--	--	--	--	53	0.3
Unnamed Spring (#2)	4	--	--	--	--	--	5.4	40
Unnamed Spring (#3)	3	--	--	265	135	168	26	17
Unnamed Spring (#4)	1	66	19	120	41	108	8.8	4.6

a/ 1: Department of Water Resources
2: Waring, G. A. (1915)
3: Berkstresser, C. F. (1968)
4: Barnes, I. and others (1967)

b/ 2.5 mg/l H_3BO_3
c/ 375 mg/l H_2SO_4, 7.7 mg/l H^+
d/ 63 mg/l OH^-

SELECTED SPRINGS

Principal Mineral Constituents (mg/l)														
Na^+	CO_3^{--}	HCO_3^-	SO_4^{--}	Cl^-	F^-	NO_3^-	B	As	Li	NH_4	PO_4	Fe	Mn	pH
173	69	--	44	256	--	--	b/	--	3.2	--	--	--	--	--
41	0	612	4.8	9.3	0.2	0	0.7	--	--	--	--	--	--	7.9
17	0	122	10	8.2	0.3	0.5	0.1	tr	0	--	0.19	0.06	0.37	8.2
9.5	0	70	1.2	3.8	0.1	0.6	0.1	--	--	--	--	--	--	7.4
263	0	154	9.5	314	5.9	0.2	11	--	--	--	--	0.03	--	8.0
11	0	153	5.4	2.3	0.1	0	0	--	--	--	--	--	--	6.2
73	8	172	33	51	0.5	0.2	0.8	0.01	0.09	0.5	0.11	0.14	0.40	8.6
53	0	145	1.3	20	--	0.2	--	--	--	--	--	--	--	7.4
26	0	187	8	6.4	0.4	0.5	0.1	0.01	0.04	--	0.21	0.02	0.49	8.2
29	10	226	1.0	16	0.2	0	1.0	0	0.04	0.3	0.15	0.74	0.31	8.5
12	0	168	13	6.9	0.3	0	0.1	--	--	--	--	--	--	7.7
123	12	252	1.0	100	0.9	0	3.9	tr	0.11	0.4	0.04	0.08	0.02	8.4
12	0	24	7.6	6.2	0.1	0.6	0	--	0	--	--	2.7	0.07	7.1
20	0	193	44	21	0.3	1.4	0	tr	0.01	0	0.02	0.01	--	8.4
11	0	78	6	5.6	0.4	0.6	0	0	0.01	0	0.1	0.09	--	7.8
945	0	2,470	5	54	9.8	0	90	0.06	0.62	1.8	0.03	0.16	0.01	7.2
9.5	0	0	8,060	1,590	0.2	12	3.6	--	--	--	0.2	0.1	--	2.2
4.7	0	180	139	1.3	0.3	3.4	0.6	0.01	0	11	0.02	0.02	0.02	7.5
5.5	0	212	160	1.1	0.2	0.9	0.7	0	0	7.7	0	0.02	0.54	7.2
12.0	0	0	5,710	0.5	--	--	3.1	--	--	1,400	--	--	--	1.8
50	0	0	0	55	0	1.0	0	--	--	--	--	--	--	11.8
36	8	195	0.4	5.8	0.1	0.2	0	--	--	--	--	--	--	8.9
5.8	5	155	10	1.9	0.1	0.6	0	tr	0	0	0	0.04	--	8.6
8.2	0	54	5.1	2.4	0.1	6.4	0	--	0	--	--	0.01	0.10	6.7



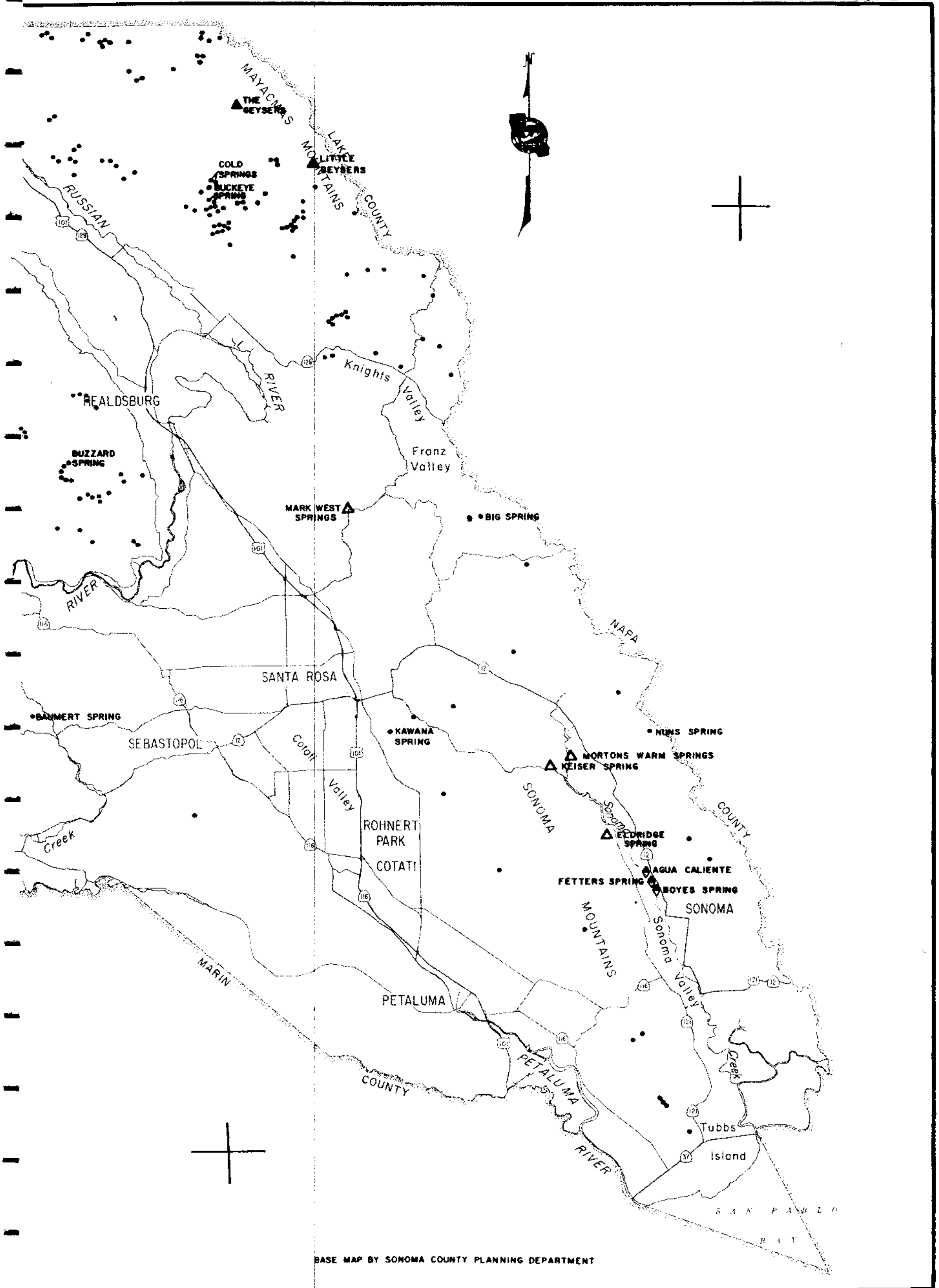
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY
GROUND WATER RESOURCES INVESTIGATION

SPRINGS

1975

SCALE OF MILES


THE GEYSERS
MAYACMAS MOUNTAINS
LAKE COUNTY
LITTLE GEYSERS
COLD SPRINGS
BUCKEYE SPRING
RUSSIAN RIVER
Knights Valley
HEALDSBURG
BUZZARD SPRING
Franz Valley
MARK WEST SPRINGS
BIG SPRING
RIVER
NAPA COUNTY
SANTA ROSA
BAUMERT SPRING
SEBASTOPOL
Cotati Valley
KAWANA SPRING
NUNS SPRING
MORTONS WARM SPRINGS
KEISER SPRING
SONOMA MOUNTAINS
Sonoma Creek
ELDRIDGE SPRING
AGUA CALIENTE
FETTERS SPRING
BOYES SPRING
SONOMA
ROHNERT PARK
COTATI
Creek
MARIN COUNTY
Sonoma Valley
PETALUMA
PETALUMA RIVER
Creek
Tubbs Island
SAN PABLO BAY
BASE MAP BY SONOMA COUNTY PLANNING DEPARTMENT

Berkstresser (1968) identified the physical and chemical characteristics of 19 springs in Sonoma County as a part of a data report on springs of the North Coast Ranges and Klamath Mountains. Data from this report are included on Tables 14 and 15.

The principal springs of Sonoma County are located on Figure 19 and are described on Table 14; mineral analyses of water from selected springs are shown on Table 15.

Total Ground Water in Storage

For the purpose of determining the amount of total ground water in storage in Sonoma County, the county has been divided into 21 ground water storage units as shown on Figure 20. Well logs for each storage unit were analyzed, and the descriptions of the subsurface materials were translated into equivalent specific yield (ESY) values. Equivalent specific yield is defined as being equal to the specific yield of a material but without the connotation of the quantity of ground water in storage. Thus, the ESY value of a material remains the same whether ground water is present under confined or unconfined conditions, or is absent. The ESY value for the deepest well log per quarter section was encoded and used as input to the GEOLOG computer program. These data, coupled with the surface area for each ground water storage unit and an equation representing the relationship between ESY values and permeability, provided a value which represented the amount of ground water in storage in each storage unit. This original value then was modified by deducting quantities for a sloping bottom and sloping ground surface of the respective ground water storage unit and deducting a volumetric amount equal to the average depth to water in each quarter township for each storage unit. The remainder was the value for the total amount of ground water in storage in the water-bearing sediments of each storage unit; these values are presented on Table 16. The values shown on the table are that of the total amount of ground water in storage to the depths shown. These values cannot be construed to be the usable ground water storage capacity because this latter value can be estimated only after performing a detailed hydrologic study of aquifer parameters, such as quantity and rate of recharge, aquifer transmissivity, pumpage, and safe yield.

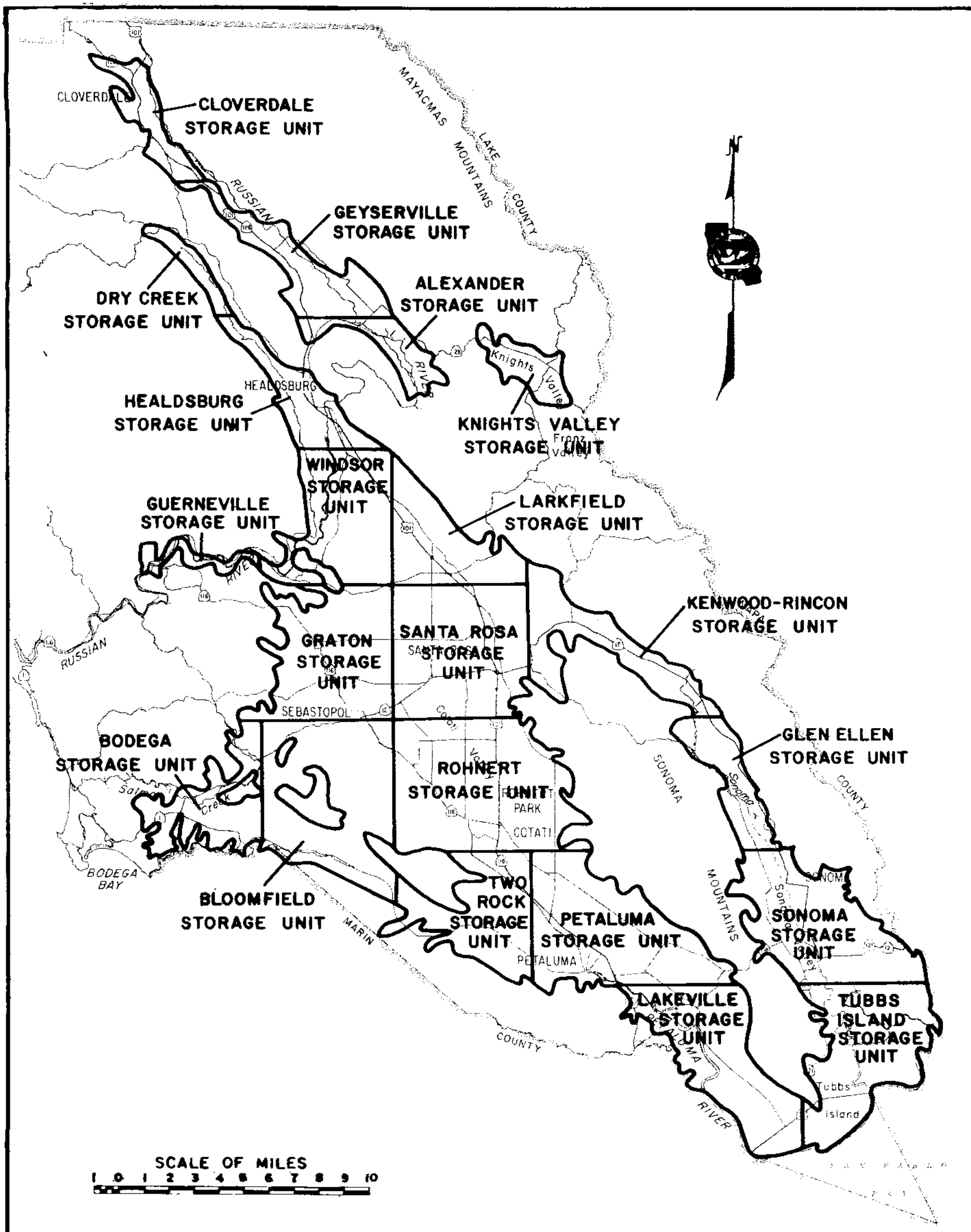
Potential for Future Ground Water Development

A potential for the development of additional ground water supplies exists in Sonoma County provided that both geology and hydrology receive careful attention. Additional supplies of potable ground water can be developed at almost any location in the ground water basins shown on Figure 12. All of these areas are underlain by water-bearing materials as shown on Plate 1. Geochemical constraints may limit the development in certain areas of the ground water basins. A discussion of these constraints is presented in Chapter VI; the areal extents of the various constraints are presented on Figures 21 and 22.

The contiguous and detached ground water areas shown on Figure 12 contain the capability of supporting additional ground water development at many localities. Wells drilled in these areas will probably meet domestic standards of quantity, but agricultural, industrial, or municipal supplies may not be adequate in some cases. Mineral constitutents in ground waters in these areas should not be a deterrent to development.

All other parts of Sonoma County are underlain by rocks that frequently are termed "nonwater-bearing"; that is, they do not predictably provide quantities of ground water to wells adequate for domestic purposes. These rocks, which are identified on Plate 1 as Jura-Cretaceous, may in a few cases, provide some water to wells; however, quality and quantity may be a constraint to development.

FIGURE 20



GROUND WATER STORAGE UNITS

Table 16
TOTAL GROUND WATER IN STORAGE

(By Ground Water Storage Unit[1/])

Ground Water Storage Unit	Surface Area (acres)	Surface Area (hectares)	Average Ground Elevation (feet)	Average Ground Elevation (meters)	Bottom Elevation (feet)	Bottom Elevation (meters)	Number of Control Wells	Average Specific Yield (percent)	Gross Ground Water Storage Capacity (thousand acre-feet)	Gross Ground Water Storage Capacity (cubic hectometers)
Cloverdale	5,430	*2,198*	300	*90*	+ 210	*+ 64*	19	17.98	50	*60*
Geyserville	10,176	*4,118*	170	*50*	- 500	*-152*	19	9.89	325	*400*
Alexander	4,736	*1,917*	150	*45*	- 320	*- 98*	18	10.95	120	*150*
Dry Creek	2,830	*1,145*	180	*55*	+ 40	*+ 12*	20	14.76	20	*25*
Healdsburg	9,180	*3,715*	100	*30*	- 110	*- 34*	26	7.78	40	*50*
Windsor	14,610	*5,913*	110	*35*	- 930	*-283*	51	9.49	1,100	*1,360*
Larkfield	11,800	*4,775*	130	*40*	- 510	*-155*	40	6.56	600	*740*
Graton	21,280	*8,612*	100	*30*	- 530	*-162*	95	13.54	2,400	*3,000*
Santa Rosa	23,500	*9,510*	80	*25*	- 960	*-293*	114	6.69	1,700	*2,100*
Bodega	10,400	*4,209*	150	*45*	- 160	*- 49*	8	12.78	500	*620*
Bloomfield	24,300	*9,834*	200	*60*	- 900	*-274*	91	15.05	2,650	*3,275*
Rohnert	30,390	*12,299*	100	*30*	- 930	*-283*	79	9.22	3,100	*3,825*
Two Rock	14,766	*5,976*	60	*20*	- 400	*-122*	40	14.25	885	*1,100*
Petaluma	21,790	*8,818*	40	*15*	- 800	*-244*	65	8.22	770	*950*
Lakeville	20,140	*8,151*	20	*6*	- 690	*-210*	11	5.51	875	*1,080*
Kenwood-Rincon	12,660	*5,124*	420	*130*	- 740	*-226*	52	6.83	1,050	*1,300*
Glen Ellen	7,936	*3,212*	270	*80*	- 150	*- 46*	30	4.87	190	*235*
Sonoma	20,600	*8,337*	50	*15*	- 930	*-283*	87	8.01	1,760	*2,170*
Tubbs Island	21,092	*8,536*	20	*6*	- 530	*-162*	8	5.51	535	*660*
Knights Valley	3,370	*1,364*	400	*120*	+ 280	*+ 85*	6	7.54	15	*20*
Guerneville	1,840	*745*	40	*10*	- 250	*- 76*	41	18.82	50	*60*
								Total	18,735	*23,080*

(By Ground Water Basin[2/])

Ground Water Basin and Subbasin	Average Specific Yield (percent)	Gross Ground Water Storage Capacity (thousand acre-feet)	Gross Ground Water Storage Capacity (cubic hectometers)
Alexander Valley	14.20	495	*610*
Alexander Area	10.42	445	*550*
Cloverdale Area	17.98	50	*60*
Santa Rosa Basin	8.51	8,335	*10,280*
Santa Rosa Plain	8.03	7,115	*8,775*
Healdsburg Area	10.67	930	*1,145*
Rincon Valley	6.83	290	*360*
Knights Valley	7.54	15	*20*
Kenwood Valley	6.83	460	*570*
Lower Russian River	18.82	160	*200*
Petaluma Valley	6.86	2,100	*2,590*
Sonoma Valley	6.76	2,660	*3,280*
Total		14,225	*17,550*

1/ Ground water storage units delineated on Figure 19.
2/ Ground water basins delineated on Figure 11.

CHAPTER VI. WATER QUALITY HAZARDS

Most of the ground water in Sonoma County is an excellent quality calcium- magnesium-bicarbonate water. However, certain areas of water quality hazards have been identified; these are depicted on Figure 21. These latter areas contain poor-quality chloride and sulfate water, waters containing excessive amounts of boron or nitrate, and ground water containing iron and/or manganese in excess of recommended public health standards. In addition to water quality hazards caused by excessive amounts of specific mineral constituents, there are also water quality hazard areas resulting from excessive total dissolved solids and hardness. Areas having these latter two problems are depicted on Figure 22.

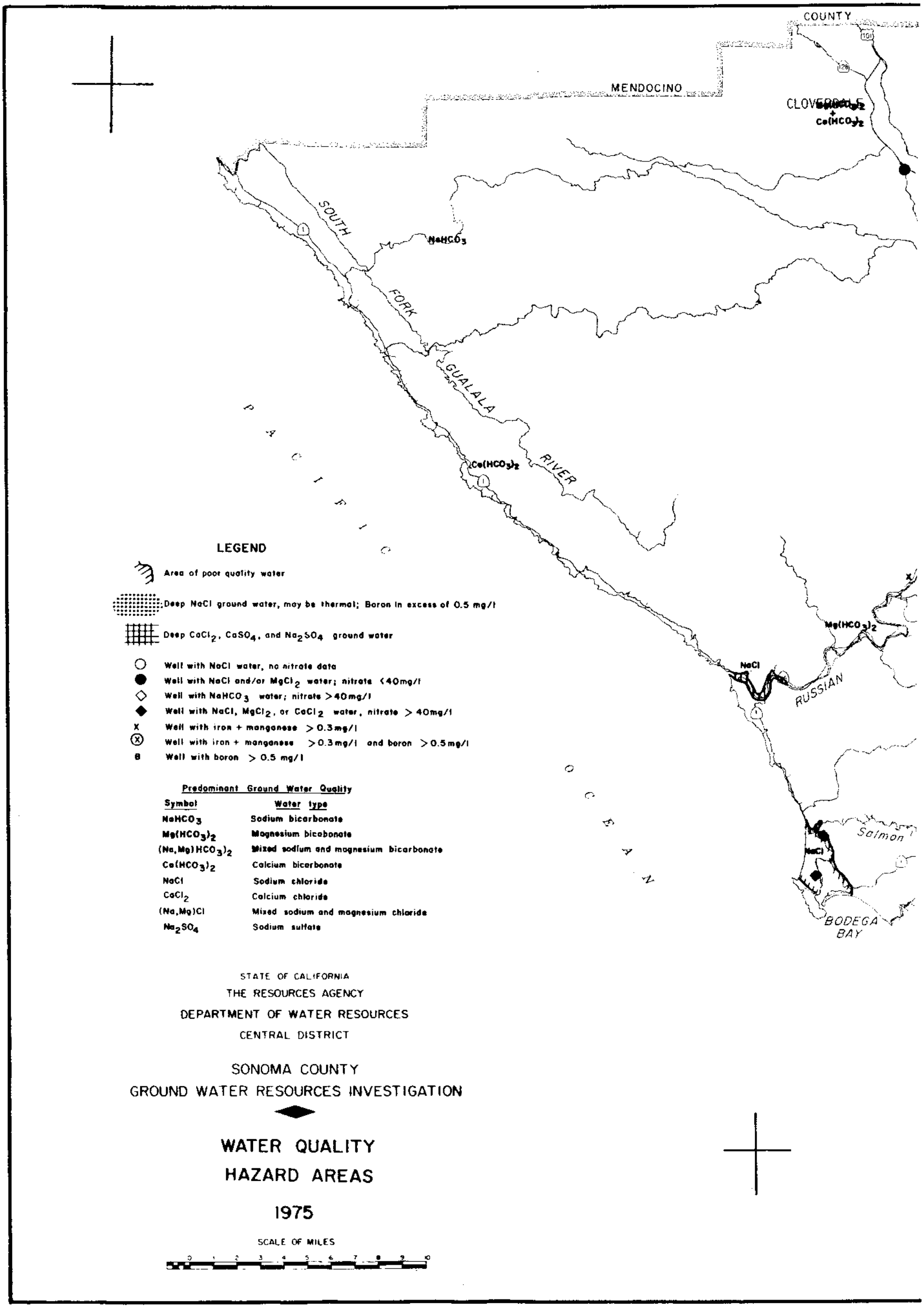
The various water quality criteria from which the upper limits of mineral constituents, total dissolved solids, and hardness are established are presented in Appendix F. Each of the principal mineralogical water quality hazards in Sonoma County is briefly discussed below. Bacteriological water quality hazards are discussed in Chapter IV; no data were developed during the current study to define possible water quality hazards as they relate to agricultural, municipal, or industrial wastes.

Boron Hazard

According to Hem (1959) and Ayers and Branson (1974), crops may be divided into three main groups depending on their sensitivity to boron. Sonoma County crops considered sensitive to boron include berries, fruit trees (apple, apricot, etc.), grapes, and nuts. Semi-tolerant crops include most field plants such as corn, grain, squash, and tomatoes; whereas tolerant crops are those such as sugar beets, alfalfa, and asparagus. Table 17 presents the ratings of irrigation water for various crops on the basis of the boron concentration in water. Boron is not considered a hazard to domestic water at the concentrations found in Sonoma County.

Concentrations of boron in excess of 0.5 mg/l have been reported from 42 wells in Sonoma County. The areal distribution of these wells is shown on Figure 21. The range of boron concentration in these wells is presented on Table 18.

Ground water containing excessive amounts of boron may be attributed to several sources. One such source is from connate water contained in marine sediments or migrating from marine sediments into materials comprising adjacent overlying ground water basins. Wells in the vicinity of Healdsburg having excessive boron (see Figure 21) may be affected by waters of connate origin.


COUNTY
MENDOCINO
CLOVERDALE
$Ca(HCO_3)_2$
SOUTH
FORK
GUALALA
RIVER
$NaHCO_3$
$Ca(HCO_3)_2$
P A C I F I C
O C E A N
$Mg(HCO_3)_2$
NaCl
RUSSIAN
Salmon
NaCl
BODEGA
BAY
LEGEND
Area of poor quality water
Deep NaCl ground water, may be thermal; Boron in excess of 0.5 mg/l
Deep $CaCl_2$, $CaSO_4$, and Na_2SO_4 ground water
Well with NaCl water, no nitrate data
Well with NaCl and/or $MgCl_2$ water; nitrate <40mg/l
Well with $NaHCO_3$ water; nitrate >40mg/l
Well with NaCl, $MgCl_2$, or $CaCl_2$ water, nitrate >40mg/l
Well with iron + manganese >0.3mg/l
Well with iron + manganese >0.3mg/l and boron >0.5mg/l
Well with boron >0.5 mg/l
Predominant Ground Water Quality
Symbol — Water type
$NaHCO_3$ — Sodium bicarbonate
$Mg(HCO_3)_2$ — Magnesium bicabonate
$(Na,Mg)HCO_3)_2$ — Mixed sodium and magnesium bicarbonate
$Ca(HCO_3)_2$ — Calcium bicarbonate
NaCl — Sodium chloride
$CaCl_2$ — Calcium chloride
(Na,Mg)Cl — Mixed sodium and magnesium chloride
Na_2SO_4 — Sodium sulfate
STATE OF CALIFORNIA
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CENTRAL DISTRICT
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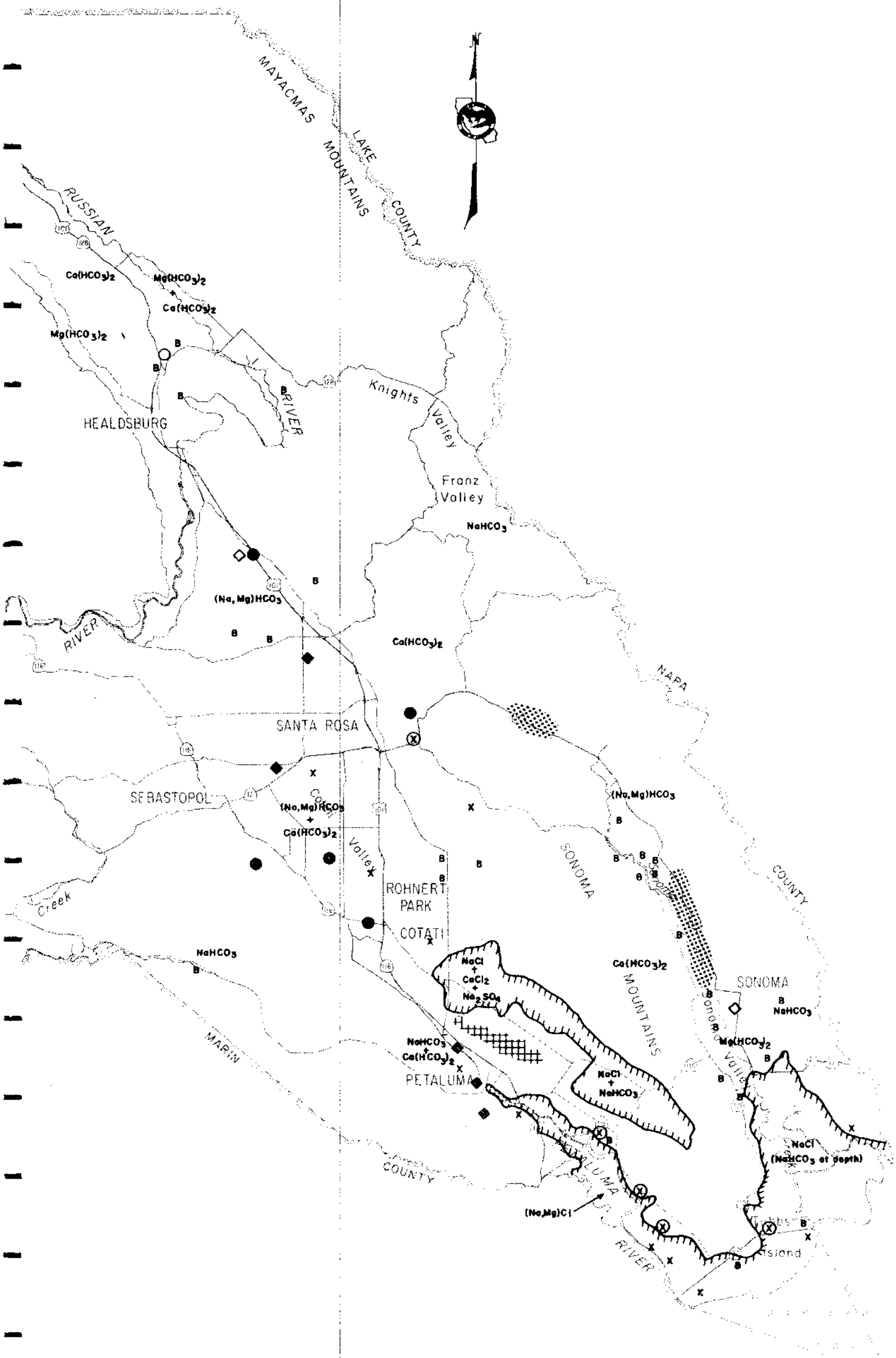
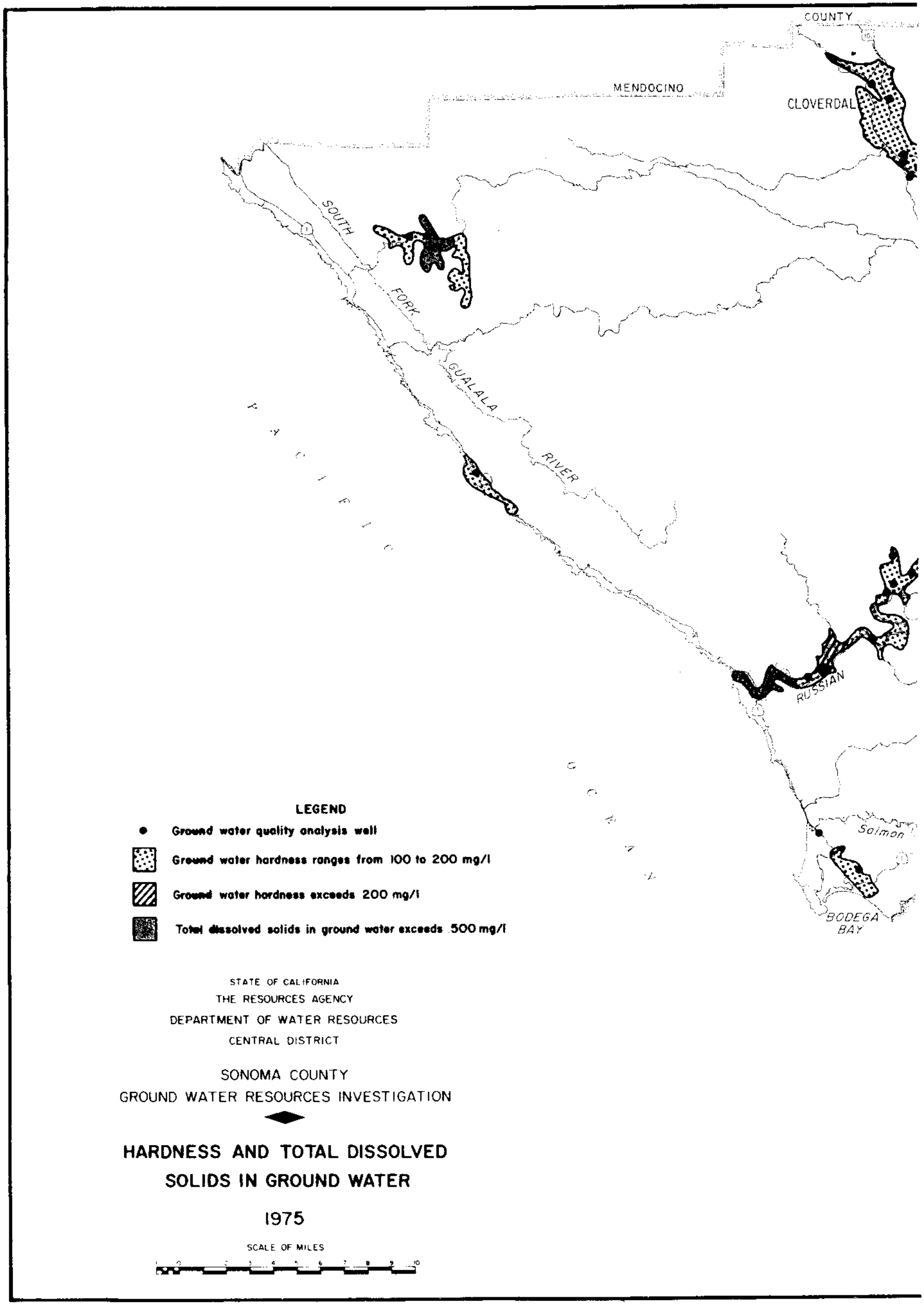
GROUND WATER RESOURCES INVESTIGATION
WATER QUALITY
HAZARD AREAS
1975
SCALE OF MILES
0 1 2 3 4 5 6 7 8 9 10



BASE MAP BY SONOMA COUNTY PLANNING DEPARTMENT



COUNTY
MENDOCINO
CLOVERDALE
SOUTH
FORK
GUALALA
RIVER
RUSSIAN
Salmon
BODEGA
BAY
LEGEND
Ground water quality analysis well
Ground water hardness ranges from 100 to 200 mg/l
Ground water hardness exceeds 200 mg/l
Total dissolved solids in ground water exceeds 500 mg/l
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT
SONOMA COUNTY
GROUND WATER RESOURCES INVESTIGATION
HARDNESS AND TOTAL DISSOLVED
SOLIDS IN GROUND WATER
1975
SCALE OF MILES

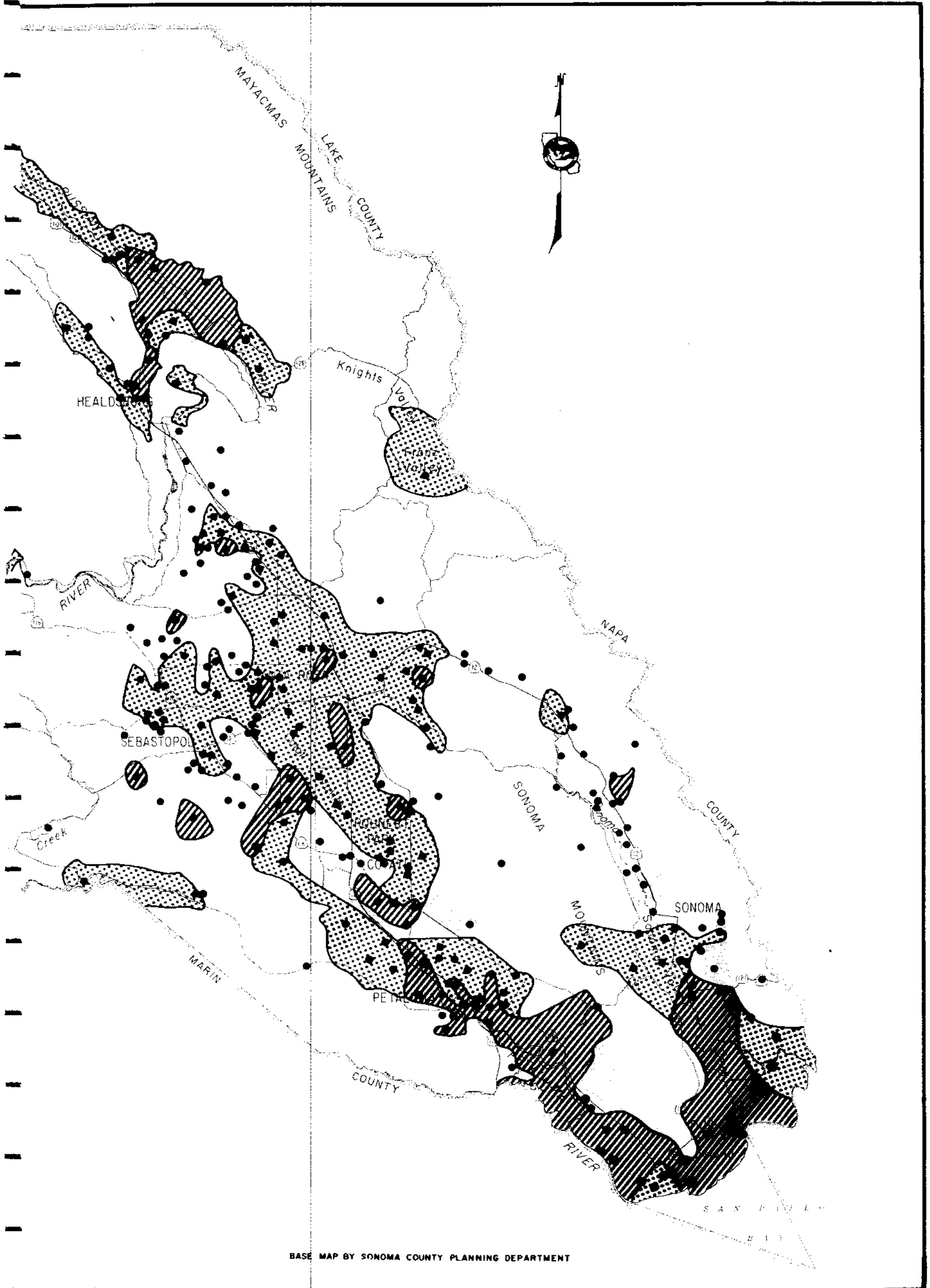

MAYACMAS
MOUNTAINS
LAKE
COUNTY
HEALDSBURG
Knights
Valley
RIVER
NAPA
SEBASTOPOL
SONOMA
COUNTY
ROHNERT
PARK
Creek
SONOMA
MOUNTAINS
MARIN
PETALUMA
COUNTY
RIVER
SAN PABLO
BAY
BASE MAP BY SONOMA COUNTY PLANNING DEPARTMENT

Table 17

BORON CONTENT FOR IRRIGATION WATER[1/]

Boron Content (mg/l)	Remarks
<0.5	Satisfactory for all crops.
0.5 - 1.0	Satisfactory for most crops; sensitive crops may show leaf injury but yields may not be affected.
1.0 - 2.0	Satisfactory for semitolerant crops. Sensitive crops usually show reduced yield and vigor.
2.0 - 10.0	Only tolerant crops produce satisfactory yields.

1/ Ayers, R. S. and Branson, R. L. (1974).

West of Dry Creek, Well No. 10N/10W-27D2 was drilled into a mass of Jura-Cretaceous ultramafic rock. The presence of 13.36 mg/l of boron is typical of ground water affected by water contained in an ultramafic mass. Wells in the southern parts of Petaluma and Sonoma Valleys contain excessive boron due to the presence of sea water which has intruded the water-bearing materials. Wells tapping thermal waters, such as those at Boyes Springs, also yield water containing excessive boron. In these instances, boron is attributed to juvenile water rising along fault zones and commingling with percolating ground water.

A few wells, such as No. 8N/9W10R1, tap the Glen Ellen Formation and do not appear to be located along any mapped fault trace. The presence of boron in this well may be due to ground water percolating laterally through old soil horizons containing large quantities of the highly soluble boron salts.

Hazardous quantities of boron in shallow wells such as No. 10N/9W-18R1, which is 14 feet (4 meters) deep, are probably due to direct infiltration of surface water containing large concentrations of boron. Table 19 presents boron concentrations in surface water available for recharge. Boron concentrations are highest during periods of low flows and, conversely, are lowest during periods of high winter runoff. Moreover, some streams draining areas of thermal springs, such as Big Sulfur Creek which drains The Geysers area, contribute significant quantities of boron to the Russian River system.

Table 18

BORON CONCENTRATION IN GROUND WATER
IN EXCESS OF 0.5 mg/l

Well Number	Depth (feet)	Depth (meters)	Geologic Formation	Maximum Reported Boron Concentration (mg/l)
3N/5W-6C1	50	15	Bay Mud Deposits	0.59
4N/5W-3C1	261	80	Older Alluvium	1.6
-34D80	-	-	Bay Mud Deposits	1.9
4N/6W-7H1	35	11	Younger Alluvium[a/]	2.3
-7H2	14	4	Younger Alluvium[a/]	3.1
-8E1	74	23	Younger Alluvium[a/]	2.2
-21Q1	464	141	Petaluma Formation	1.1
-27N1	222	68	Younger Alluvium and Petaluma Formation	0.6
-27R1	736	224	Younger Alluvium and Petaluma Formation	0.9
4N/7W-2D1	62	19	Younger Alluvium[a/]	1.0
5N/5W-9M2	257	78	Older Alluvium	1.0
-20C1	125	38	Older Alluvium	0.56
-20R1	504	154	Older Alluvium and Huichica Formation (?)	4.8
-31A1	408	124	Older Alluvium	6.6
5N/6W-2A2	350	107	Glen Ellen Formation[b/]	11.0
-12F1	113	34	Older Alluvium	1.2
-13K1	150	46	Older Alluvium	4.4
-25P1	171	52	Older Alluvium	1.3
5N/7W-34G1	230	70	Younger Alluvium	0.63
5N/8W-21L1	140	43	Merced Formation	1.5
5N/9W-3G1	1,010	308	Merced Formation and Franciscan Formation	0.54
6N/6W-15K1	75	23	Younger Alluvium	0.54
-16B2	211	64	Glen Ellen Formation	7.7
-16H1	-	-	Glen Ellen Formation	6.2
-16J2	-	-	Glen Ellen Formation	7.7
-23M2	165	50	Older Alluvium	2.5
-26E1	304	93	Older Alluvium	3.2
6N/7W-16D1	38	12	Sonoma Volcanics	0.64
-17D1	-	-	Sonoma Volcanics	1.2
-17E1	650	198	Sonoma Volcanics	2.0
6N/10W-36N80	155	47	Merced Formation	1.5
6N/11W-22K1	-	-	Marine Terrace Deposits	1.4
7N/8W-24A4	1,000	305	Alluvium and Sonoma Volcanics	
8N/9W-13J80	400	122	Alluvium and Glen Ellen Formation	1.4
-27K1	333	101	Alluvium and Glen Ellen Formation	1.04
-36K1	1,325	404	Alluvium and Glen Ellen Formation	2.44
-36P1	1,048	319	Alluvium and Glen Ellen Formation	4.0
9N/9W-4E1	117	36	Younger Alluvium	14.0
-4E2	32	10	Younger Alluvium	4.4
-9L1	90	27	Glen Ellen Formation	1.0
10N/9W-32R3	245	75	Younger Alluvium and Glen Ellen Formation (?)	0.62

a/ Affected by sea water intrusion.
b/ Thermal well at Boyes Hot Spring.

Table 19

BORON CONCENTRATIONS IN

SURFACE WATER AVAILABLE FOR RECHARGE

Stream	Sampling Station Location	Discharge (cfs)	(cumec)	Boron Concentration (mg/l)
Russian River	8N/10W-32C	20,800 246	589.2 6.9	0.18 0.83
	9N/9W-22H	14,500 228	410.7 6.5	0.17 0.93
Unnamed Creek Tributary to Dry Creek	9N/9W-20H	10	0.3	0.58
Warm Springs Creek	10N/10W-18	- -	- -	0.10 2.8
Dry Creek	10N/11W-11	-	-	0.53
Big Sulfur Creek	11N/11W-5	8	0.2	0.51

Sodium Hazard

Water with a relatively high concentration of sodium ion will tend to deflocculate, or "puddle", soils and form a hard crust after irrigating; hence, it results in adverse effects on tilth, permeability, and infiltration. The degree of sodium hazard in ground water is determined by its Adjusted Sodium Adsorption Ratio (ASAR). This ratio is computed by the following formula:

$$ASAR = \frac{Na^+}{\sqrt{1/2(Ca^{++}+Mg^{++})}} \left[1 + (8.4 - pHc)\right]$$

where the values of the mineral constituents are reported in milliequivalents per liter (me/l) and the quantity pHc is determined from the values shown on Table 20. The concept of the ASAR is similar to that of the Sodium Adsorption Ratio, with the addition of the effects by carbonate and bicarbonate ions. The ASAR evaluates the tendency of irrigation water to dissolve lime from the soil (when pHc values are above 8.4) or precipitate lime from irrigation water when the pHc value is below 8.4.

Table 20

CALCULATION OF VALUE FOR pHc 1/

(in milliequivalents per liter)

Concentration of Ca^{++}+ Mg^{++}+ Na^{+}	"X"	Concentration of Ca^{++}+ Mg^{++}	"Y"	Concentration of CO_3^{--}+ HCO_3^{-}	"Z"
.5	2.11	.05	4.60	.05	4.30
.7	2.12	.10	4.30	.10	4.00
.9	2.13	.15	4.12	.15	3.82
1.2	2.14	.20	4.00	.20	3.70
1.6	2.15	.25	3.90	.25	3.60
1.9	2.16	.32	3.80	.31	3.51
2.4	2.17	.39	3.70	.40	3.40
2.8	2.18	.50	3.60	.50	3.30
3.3	2.19	.63	3.50	.63	3.20
3.9	2.20	.79	3.40	.79	3.10
4.5	2.21	1.00	3.30	.99	3.00
5.1	2.22	1.25	3.20	1.25	2.90
5.8	2.23	1.58	3.10	1.57	2.80
6.6	2.24	1.98	3.00	1.98	2.70
7.4	2.25	2.49	2.90	2.49	2.60
8.3	2.26	3.14	2.80	3.13	2.50
9.2	2.27	3.90	2.70	4.0	2.40
11	2.28	4.97	2.60	5.0	2.30
13	2.30	6.30	2.50	6.3	2.20
15	2.32	7.90	2.40	7.9	2.10
18	2.34	10.00	2.30	9.9	2.00
22	2.36	12.50	2.20	12.5	1.90
25	2.38	15.80	2.10	15.7	1.80
29	2.40	19.80	2.00	19.8	1.70
34	2.42				
39	2.44				
45	2.46				
51	2.48				
59	2.50				
67	2.52				
76	2.54				

1/ pHc = "X" + "Y" + "Z"
After Ayers and Branson (1975)

A rough determination of sodium hazard can be ascertained by relating the ASAR value and the specific conductance of the water as measured in micromhos. This relationship is presented on Table 21. Ideally, water intended for agricultural use should have only a minimum concentration of sodium ions and consequently a larger amount of calcium and magnesium ions. This is just the opposite of the ideal water intended for domestic use.

Sodium is the dominant cation in much of the ground water in Sonoma County. Excessive amounts of this ion may cause a significant decrease in the permeability of agricultural soils receiving irrigation water. The presence of excessive amounts of sodium ion in ground water is due to the phenomenon of cation exchange as the water percolates through clay-rich sediments. Ground water containing calcium ion reacts with the clays according to the formula:

$$2\ NaX + Ca^{++} = CaX_2 + 2\ Na^{+}$$

where X represents a unit of exchange capacity in the solid phase material. Calcium ion becomes adsorbed by the clay minerals in exchange for sodium ion, which is released to the ground water. The analysis from Well No. 6N/7W-17E1 on Table 22 is typical of ground water that has undergone this cation exchange.

Salinity Hazard

One measure of the salinity hazard in agricultural water is its electrical conductivity. Plants sensitive to salinity are those which require a specific conductance of less than 250 micromhos; plants in this group include berries, fruit trees, and clover. Moderately tolerant crops are those which can tolerate water with specific conductances of up to 750 micromhos; plants in this group include grapes and most vegetables and forage crops. Tolerant crops are those which can use water with conductivities greater than 750 micromhos; these include asparagus and hay.

The salinity of domestic water supplies is measured by the content of chloride ion. In this case, the California Administrative Code recommends that the maximum concentration of chloride ion in drinking water be 250 mg/l. Water containing more than 250 mg/l of chloride ion usually has a noticeably salty taste. None of the major water purveyors deliver water containing chloride in excess of 250 mg/l.

Table 21

SODIUM ADSORPTION VALUES FOR VARYING CONDUCTIVITIES AND SODIUM HAZARD CONDITIONS 1/

Sodium Hazard	Electrical Conductivity (micromhos) 0-250	250-750	750-2250	2250+
Low	0-9	0-7	0-5	0-3
Medium	9-15	7-14	5-11	3-7
High	15-24	14-20	11-16	7-12
Extreme	24+	20+	16+	12+

1/ After Hem (1959)

Example of Determination of Sodium Hazard in Water

1. Water Analysis:

   Ca^{++} = 0.21 me/l CO_3^{--} = 0.58 me/l
   Mg^{++} = 0.08 " HCO_3^{-} = 2.81 "
   Na^{+} = 4.45 " Conductivity = 454 micromhos

2. Determination of SAR:

$$SAR = \frac{Na^+}{\sqrt{1/2(Ca^{++}+Mg^{++})}} = \frac{4.45}{\sqrt{1/2(0.21 + 0.08)}} = 11.71$$

3. Determination of pHc (from Table 21):

   "X": $Ca^{++} + Mg^{++} + Na^{+}$ = 0.21+0.08+4.45 = 4.74; "X" = 2.21
   "Y": $Ca^{++} + Mg^{++}$ = 0.21 + 0.08 = 0.29; "Y" = 3.84
   "Z": $CO_3^{--} + HCO_3^{-}$ = 0.58 + 2.81 = 3.39; "Z" = 2.48
   pHc = "X" + "Y" + "Z" = 2.21 + 3.84 + 2.48 = 8.53

4. Determination of Adjusted SAR:

$$ASAR = SAR\left[1 + (8.4 - pHc)\right] = 11.71\left[1 + (8.4 - 8.53)\right] = 10.19$$

5. Determination of sodium hazard (from Table 22):

   Conductivity is in range of 250 to 750 micromhos.

   Adjusted sodium adsorption is in range of 7 to 14.

   Expected sodium hazard of water is MEDIUM.

Table 22

SODIUM HAZARD IN GROUND WATER

Well Number	Depth (feet)	Depth (meters)	Geologic Formation	Adjusted SAR Value[a/]	Maximum Reported Electrical Conductivity (micromhos)	Sodium Hazard Medium	Sodium Hazard High	Sodium Hazard Extreme
3N/6W-3C1	-	-	Bay Mud Deposits	17.2	4,420			x
-11B1	250	76	Bay Mud Deposits	20.5	2,120			x
4N/5W-14D2	1,620	494	Huichica Formation (?)	15.2	1,260		x	
-28Q1	-	-	Bay Mud Deposits	24.9	3,310			x
-34D1	200	61	Bay Mud Deposits	21.6	2,990			x
-34D80	-	-	Bay Mud Deposits	21.0	2,750			x
4N/6W-7H2	14	4	Younger Alluvium[b/]	42.3	5,260			x
-21F80	162	49	Petaluma Formation	13.2	840		x	
-21Q1	464	141	Petaluma Formation	18.4	1,490			x
-33R1	175	53	Bay Mud Deposits	25.2	8,300			x
4N/7W-2D1	62	19	Younger Alluvium[b/]	25.8	26,800			x
5N/5W-9M2	257	78	Older Alluvium	23.9	630			x
-20R1	504	153	Older Alluvium and Huichica Formation (?)	19.5	1,020			x
-31A1	408	124	Older Alluvium	23.9	854			x
-31A3	56	17	Older Alluvium	33.5	4,710			x
-31B1	56	17	Older Alluvium	32.0	5,010			x
-33K1	190	58	Older Alluvium	46.2	7,560			x
-33K3	-	-	Older Alluvium	36.5	20,571			x
5N/6W-2A2	350	107	Glen Ellen Formation	18.8	1,350			x
-33H80	575	175	Petaluma Formation	13.0	1,400		x	
5N/7W-34E2	280	85	Younger Alluvium	23.9	880			x
-34G2	280	85	Younger Alluvium	22.4	854			x
5N/8W-21L1	140	43	Merced Formation	19.5	584			x
5N/9W-3G1	1,010	308	Merced Formation and Franciscan Formation	12.0	550	x		
6N/6W-16B2	211	64	Glen Ellen Formation	14.3	672		x	
-16H1	-	-	Glen Ellen Formation	11.8	550	x		
-26E1	304	93	Older Alluvium	8.3	458	x		
6N/7W-17E1	650	198	Sonoma Volcanics	10.2	454	x		
6N/8W-16G	-	-	Glen Ellen Formation	31.5	4,420			x
7N/9W-13R1	375	114	Glen Ellen Formation	11.6	600	x		
7N/11W-16	-	-	Younger Alluvium[b/]	105.2	9,400			x
8N/9W-36P1	1,048	319	Alluvium and Glen Ellen Formation	20.4	952			x
9N/8W-7Q1	490	149	Glen Ellen Formation	16.0	611		x	

a/ Adjusted SAR = $\frac{Na^{+}}{\sqrt{1/2\,(Ca^{++} + Mg^{++})}}\left[1 + (8.4 - pHc)\right]$, constituents in milliequivalents per liter and value of pHc from Table 21.

b/ Affected by sea water intrusion.

Saline ground water found in Sonoma County is attributable to a numer of different sources. In alluvial areas adjacent to bodies of salt water, such as the lower Russian River Valley, lower Petaluma Valley, and Bodega Bay area, salt water wedges have moved inland along the basal portions of freshwater aquifers, causing sea water intrusion. The analysis from Well No. 7N/11W-16 shows a chloride concentration of 2,920 mg/l on Table 23, a condition that is indicative of wells which tap intruded aquifers. The distance inland that the salt water wedge extends depends on the amount of pumpage from the aquifer and the amount of fresh water that is available locally to repel the intrusion. Areas of sea water intrusion are shown on Figure 21. Almost all wells in these intruded areas produce sodium-magnesium chloride water of questionable suitability.

Sodium chloride water also is reported from some wells tapping the Petaluma Formation, as well as from a few other formations of marine origin. Nine inland wells yield sodium chloride water; analyses from selected wells of this group are presented on Table 23. The source of the chloride ion has not been determined for most of these wells; those located close to marine sediments presumably derive their chloride concentration from those sediments.

Iron and Manganese Hazard

The presence of excessive iron and manganese in ground water is reported to be fairly widespread throughout Sonoma County. Both of these impurities can impart a metallic taste to water or to food prepared with such water. The metallic impurities may also stain fixtures, fabrics, and utensils. Soaps and detergents cannot remove such stains, and bleaches serve only to intensify them. After a prolonged time, the iron and manganese deposits which build up in pressure tanks, water heaters, and pipes reduce the available quantity and pressure of the water supply.

In the past, many mineral analyses of water from wells did not include these two constituents because of difficulties in preparing samples so that the two minerals would not precipitate before analysis. Hence, only a few analyses show iron in excess of the 0.3 mg/l recommended limit or manganese in excess of the 0.5 mg/l recommended limit. Wells producing water above the recommended limits are shown on Figure 21.

The California Administrative Code provides for limits in the amount of iron and manganese in drinking water. The limits are for esthetic and taste reasons, and excessive iron and manganese do not constitute a serious detriment to the purity of drinking water. Excessive amounts of iron in water combine with oxygen

Table 23

SALINITY HAZARD IN GROUND WATER

Well Number	Depth (feet)	Depth (meters)	Geologic Formation	Maximum Reported Chloride Ion Concentration (mg/l)	Maximum Reported Electrical Conductivity (micromhos)	Salinity Hazard[a] High	Salinity Hazard[a] Extreme
3N/5W-6C1	50	15	Bay Mud Deposits	173	1,200	x	
3N/6W-1Q1	225	69	Bay Mud Deposits	170	1,370	x	
-3C1	-	-	Bay Mud Deposits	1,342	4,420		x
-11B1	250	76	Bay Mud Deposits	364	2,120	x	
4N/5W-2Q2	300	91	Huichica Formation (?)	139	1,050	x	
-3C1	261	80	Bay Mud Deposits	188	1,780	x	
-14D1	540	165	Huichica Formation (?)	121	957	x	
-14D2	1,620	494	Huichica Formation (?)	148	1,260	x	
-28Q1	-	-	Bay Mud Deposits	808	3,310		x
-37B1	-	-	Bay Mud Deposits	314	1,880		x
-34D1	200	61	Bay Mud Deposits	730	2,990		x
-34D80	-	-	Bay Mud Deposits	561	2,750		x
4N/6W-7H1	35	11	Younger Alluvium	74	1,230	x	
-7H2	14	4	Younger Alluvium[b]	1,360	5,260		x
-8E1	74	23	Younger Alluvium	48	927	x	
-21F80	162	49	Petaluma Formation	78	840	x	
-21Q1	464	141	Petaluma Formation	264	1,490	x	
-27N1	222	68	Younger Alluvium and Petaluma Formation	143	1,190	x	
-27R1	736	224	Younger Alluvium and Petaluma Formation	156	1,210	x	
-33R1	175	53	Bay Mud Deposits	3,270	10,600		x
4N/7W-2D1	62	19	Younger Alluvium[b]	10,300	26,900		x
-4F1	184	56	Sonoma Volcanics	143	1,280	x	
5N/5W-28N1	130	40	Older Alluvium	188	791	x	
-31A1	408	124	Older Alluvium	87	957	x	
-31A3	56	17	Older Alluvium	1,360	4,710		x
-31B1	56	17	Older Alluvium	1,480	5,010		x
-33K1	190	58	Older Alluvium	2,600	7,560		x
-33K3	-	-	Older Alluvium	7,582	20,571		x
5N/6W-2A2	350	107	Glen Ellen Formation	392	1,550	x	
-30D1	155	47	Petaluma Formation	176	1,510	x	
-33H80	575	175	Petaluma Formation	203	1,400	x	
5N/7W-8D1	-	-	Merced Formation	112	910	x	
-8D3	138	42	Merced Formation	204	1,100	x	
-10Q1	462	141	Petaluma Formation	735	2,760		x
-20B1	600	183	Merced Formation (?)	176	891	x	
-20C1	688	210	Merced Formation (?)	202	988	x	
-20C2	62	19	Younger Alluvium	590	2,370	x	
-20C3	50	15	Younger Alluvium	194	1,210	x	
-29H1	244	74	Merced Formation	125	960	x	
-29N1	244	74	Merced Formation	138	1,000	x	
-34E2	280	85	Younger Alluvium	76	880	x	
-34G1	230	70	Younger Alluvium	362	1,570	x	
-34G2	280	85	Younger Alluvium	76	854	x	
6N/7W-18K1	250	76	Alluvial Fans and Older Alluvium	58	816	x	
-18R1	250	76	Alluvial Fans and Older Alluvium	70	1,050	x	
6N/8W-26	-	-	Glen Ellen Formation (?)	625	2,500	x	
7N/8W-13C1	780	238	Glen Ellen Formation (?) and Sonoma Volcanics (?)	104	766	x	
-15G1	65	20	Younger Alluvium	50	810	x	
-30P1	-	-	Glen Ellen Formation	145	1,100	x	
7N/11W-15	-	-	Younger Alluvium	14	312		x
-16	-	-	Younger Alluvium[b]	2,920	9,400		x
8N/9W-36P1	1,048	319	Alluvium and Glen Ellen Formation	110	952	x	
9N/9W-4E1	117	36	Younger Alluvium	97	776	x	
10N/9W-20B1	337	103	Younger Alluvium and Franciscan Formation (?)	20	890	x	

a/ High Hazard: Conductivity ranges from 750 to 2,250 micromhos.
Extreme Hazard: Conductivity in excess of 2,250 micromhos.

b/ Affected by sea water intrusion.

from the air to form a reddish-brown insoluble precipitate which resembles rust. Manganese acts in a similar manner, but forms a brownish-black precipitate.

Under certain conditions dissolved iron and oxygen in the water promote the growth of iron bacteria. The result is a slimy, rust-colored mass which clings to the interior walls of tanks and pipes. These bacteria can also impart an unpleasant taste and odor to the water and discolor fabrics.

Iron and manganese can be removed from water supplies by a combination of chlorination and fine filtration. The chlorine oxidizes the iron and manganese to form insoluble precipitates and kills any iron bacteria present. The filter then removes the iron and manganese precipitates, leaving the water clear and potable.

Iron is one of the most abundant mineral constituents of rocks and soils. In sandstones, iron oxide, carbonate, and hydroxide are often present in the cementing material in appreciable percentages. Iron also is present as oxide, carbonate, and sulfide in shales. In addition to solution from natural sources, iron also may be added to ground water from its contact with well casing, pump parts, piping, storage tanks, and other iron objects which come in contact with the water. Suspended sediment in surface waters also may contain iron.

Iron occurs in water at two levels of oxidation, either as bivalent ferrous ion (Fe^{++}) or as trivalent ferric ion (Fe^{+++}). The chemical behavior of the two forms is somewhat different, although both may be present in the same solution under certain circumstances. Under reducing conditions, iron in natural ground water will tend to be in the ferrous state. Ferrous salts, however, are unstable in the presence of oxygen or air. They are changed to the ferric state through oxidation when natural water containing both ferrous and bicarbonate ions comes in contact with air. In this situation, insoluble ferric hydroxide precipitates and carbon dioxide gas is liberated according to the following formula:

$$4Fe^{++} + 8HCO_3^- + 2H_2O + O_2 \longrightarrow 4Fe(OH)_3 + 8CO_2$$

Sedimentary rocks frequently contain manganese oxides and hydroxides. These constituents have been concentrated through the removal of more soluble minerals and frequently are found in association with iron oxides. There also is a tendency for manganese to accumulate in soils that are formed from rock weathering. This condition is true whether the soils are present-day or whether they are old soil horizons that now are buried.

Manganese found in ground water is probably most often the result of solution of manganese from soils and sediments aided by bacteria. Like iron, manganese occurs in more than one state of oxidation. The oxidation states of manganese in ground water are the bivalent, Mn^{++}, and quadrivalent, Mn^{+4}, states. Manganese can also occur in more highly oxidized states (Mn^{+6} and Mn^{+7}), but it is not normally encountered in these forms in natural water. Under reducing conditions, manganese can be taken into solution in ground water containing carbon dioxide in a manner analogous to iron. In the quadrivalent form as manganic hydroxide, $Mn(OH)_4$, manganese is nearly insoluble, and it is carried in colloidal suspension in a manner similar to ferric hydroxide. Thus, like iron, when ground water containing both manganous and bicarbonate ions comes in contact with air, an insoluble manganic hydroxide precipitates and carbon dioxide is liberated according to the following formula:

$$2Mn^{++}+4HCO_3^{-}+2H_2O+O_2 \longrightarrow 2Mn(OH)_4+4CO_2$$

In some parts of California, water rich in iron and manganese occurs near the bottoms of various individual aquifers. Because iron and manganese are relatively heavy, they tend to settle in an aquifer until they are concentrated just above a lower clay member. Hence, water drawn from a well perforated near the bottom of an aquifer would tend to have greater concentrations of iron and manganese than another well perforated at a higher zone in the same aquifer.

Nitrate Hazard

Hem (1959) reported on a number of studies of nitrate in water supplies. These studies linked nitrate in ground water to methemoglobinemia, or cyanosis, in infants whose feeding formulas are mixed with these waters. Waters containing an excessive amount of nitrate ion may also contain nitrite ion in excess of 1 mg/l, which according the the U. S. Environmental Protection Agency (1973) is even more hazardous to infants.

Nitrate compounds in ground water frequently may be attributed to pollution from surface sources such as septic tanks or live-stock areas. Because of this situation, sanitary seals in water wells used for domestic purposes are mandatory. Analyses of ground water in Sonoma County indicate that nine wells yield ground water containing nitrate ion in excess of the California Administrative Code recommended limit of 45 mg/l (10 mg/l expressed as nitrogen); the locations of the wells are shown on Figure 21.

Total Dissolved Solids Hazard

The amount of total dissolved solids in water indicates the total mineralization of the water. All excellent quality water contains less than 500 mg/l total dissolved solids. Water containing an excessive amount of total dissolved solids may also be expected to exhibit other water quality hazards, usually excess chloride ion. Ground water in Sonoma County ranges in total dissolved solids from a low of 129 mg/l at Well No. 11N/10W-33G1, which produces an excellent quality calcium bicarbonate water from terrace materials, to a high of 4,301 mg/l at Well No. 5N/7W-24B1, which produces an unacceptable quality water that has been affected by sea water intrusion. Areas of excessive total dissoved solids are shown on Figure 22.

Hardness Hazard

Ground water containing calcium and magnesium salts is divided into two general hardness classifications: carbonate and noncarbonate. Carbonate hardness becomes apparent after water has been heated. Heating reconstitutes the soluble calcium and magnesium bicarbonates into precipitates of insoluble carbonates. The precipitates adhere to heated surfaces, such as the inside of water heaters and hot water pipes, and ultimately cause a reduction in the capacity of the fixture. Noncarbonate hardness is not affected by heat, as it is principally caused by the presence of calcium sulfate. Both forms of hardness reduce the cleansing ability of many soaps and detergents.

Water softening is a process for the removal of the hardness-forming mineral constituents in water. Most domestic water softeners are of the ion-exchange type. In this process, the calcium and magnesium ions are adsorbed by an ion-exchange material in exchange for sodium ions. The resulting water then is relatively rich in sodium ion and is termed "soft".

Hardness of ground water is the major domestic and municipal water quality hazard in Sonoma County. Ground water in the county ranges from very soft to extremely hard. Three hardness ranges are depicted on Figure 21: Soft waters are those with a hardness of less than 100 mg/l; moderately hard waters are those with a hardness range of from 101 to 200 mg/l; and hard waters are those which have a hardness in excess of 200 mg/l.

Extremes of ground water hardness are illustrated by the analysis of very soft water from Well No. 5N/6W-30D1, which has a total hardness of 8 mg/l. In contrast, the analyses from Well No. 4N/6W-33R1 indicate that this is a very hard water; the total hardness is 1,970 mg/l and the noncarbonate hardness is 1,500 mg/l.

APPENDIX A

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Appendix B

GLOSSARY OF GEOLOGIC, HYDROLOGIC, AND RELATED TERMS

A

Acidic. A descriptive term applied to those igneous rocks that contain more than 66% silica.

Adsorb. To adhere in an extremely thin layer to the surface of a solid body.

Agglomerate. A pyroclastic rock containing a predominance of rounded fragments greater than 32 mm. in diameter.

Aggradation. The process of building up a surface by deposition.

Amphibole. A dark-colored rock-forming group of minerals which includes hornblende, actinolite, and glaucophane.

Amphibolite. A crystalline rock consisting mainly of amphibole and plagioclase. Quartz is absent or present in small amounts only.

Andesite. A volcanic rock composed of plagioclase and one or more mafic constituents.

Anion. A negatively charged ion, e.g. OH^-.

Anticline. A fold or arch in rock strata, dipping in opposite directions from an axis.

Aplite. A dike rock consisting almost entirely of light-colored mineral constituents and having a characteristic fine-grained granitic texture.

Aquifer. A part of a geologic formation containing sufficient saturated material to yield significant quantities of water to wells and springs, e.g. a sand stratum.

Arkosic sandstone. A sandstone in which much feldspar is present. This may range from unassorted products of granular disintegration of medium-grained granite to a partly sorted river-laid or even marine sandstone.

Artesian. Synonymous with confined.

Ash. Volcanic dust and particles less than 4 mm. in diameter.

B

Bailer Test. A method of estimating the yield of a well by cyclic bailing of the well.

Basalt. A fine-grained, dark-colored extrusive igneous rock. A solidified lava.

Basic. A descriptive term for those igneous rocks that are compari-tively low in silica content.

Bivalent. 1. An ion with a double electrical charge; 2. Having a valence of two, e.g. Fe^{++}, CO_3^{--}, etc.

Boulder. A rounded rock fragment larger than 256 mm. in diameter.

Breccia. A rock made up of highly angular, coarse fragments.

C

Capillary Fringe. The zone immediately above the water table in which all or some of the pores are filled with water that is under less than atmospheric pressure and that is continuous with the water below the water table.

Cation. A positively charged ion, e.g. H^+.

Cation Exchange. Replacement of ions adsorbed, or exposed at the surface of a solid, by ions from a solution. Also called base exchange.

Chert. A compact siliceous rock of sedimentary origin.

Cinder. Volcanic particles in the range from 4 to 32 mm. in diameter.

Claypan. A stratum of stiff, relatively impervious clay which is not cemented. It becomes plastic when mixed with water and it differs from hardpan.

Cobble. A rounded rock fragment between 64 and 256 mm. in diameter.

Coliform. A type of bacteria that thrives in the digestive tracts of warm-blooded animals.

Colloid. A substance that is exceedingly fine-grained and when apparently dissolved in water, forms a gelatinous mass.

Confining Bed. A body of relatively impermeable material over-lying a more permeable aquifer. Also called an aquitard or aquiclude.

Conglomerate. A cemented rock containing rounded fragments corre-sponding in size to gravel.

Coquina. Soft porous limestone composed of a mass of broken shells.

D

Deflocculate. To convert into very fine particles.

Detritus. Fragmental material, such as sand, silt, and mud, derived from older rocks by disintegration.

Diabase. A rock of basaltic composition in which lath-shaped feld-spar crystals are embedded in a matrix of fine-grained pyroxene crystals.

Diatomite. An earthy deposit composed of nearly pure silica and consisting of the shells of microscopic algae called diatoms.

Diorite. An intrusive igneous rock composed of the minerals feldspar and hornblende, biotite, or pyroxene.

Distal. Remote from the point of origin.

Drawdown. The vertical distance from the static water level in a well to the pumping level.

E

Eclogite. A granular metamorphic rock composed essentially of garnet and pyroxene.

Electrical Conductivity. Synonymous with specific conductance.

Embayment. A coastline area that has undergone sufficient subsi-dence to receive a thick succession of sediments.

Eolian. Of, relating to, formed by, or deposited from the wind.

Extrusive. Said of a rock that has been formed on the ground surface from the solidification of molten lava.

F

Fault. A fracture, or fracture zone, along which there has been displacement of the two sides relative to one another parallel to the fracture. This displacement may be a few inches or many miles.

Faulted. Affected by movement along a fault.

Feldspar. A group of abundant, light-colored rock-forming minerals. Includes orthoclase, plagioclase, and microcline.

Ferrous. Bivalent iron, Fe^{++}.

Ferric. Trivalent iron, Fe^{+++}.

Fetid. Having a disagreeable odor caused by decomposition of organic matter.

Fissile. The property of splitting easily along closely spaced parallel planes.

Flocculate. To separate into small lumps.

Floodplain. A strip of relatively smooth land bordering a stream, built of sediments carried by the stream.

Friable. Easily crumbled.

G

Gabbro. A coarse-grained, dark colored igneous rock consisting of feldspar and pyroxene. Olivine may be present; quartz is absent.

Gaining Stream. A stream which receives water from the ground water body.

Gastropod. A member of the mollusc family and includes both land and marine snails.

Geohydrology. The science of relating geologic factors to hydro-logic phenomena.

Geomorphic Province. A major geologic and landform unit. There are 11 geomorphic provinces in California, such as the Coast Ranges, Great Valley, Sierra Nevada provinces, etc.

Geosyncline. A large trough that subsided deeply throughout a long period of time in which a thick succession of stratified marine sediments accumulated.

Glauconite. A green mineral commonly occurring in sandstones of marine origin.

Glaucophane. A bluish-colored amphibole occurring in metamorphic rocks.

Granitic Rock. A coarse-grained igneous rock including granite, granodiorite, diorite, granite porphyry, diorite porphyry, and gabbro.

Granodiorite. A coarse-grained igneous rock consisting of quartz, feldspar, biotite, hornblende, and pyroxene.

Gravel. An accumulation of rounded rock fragments larger than 2 mm. in diameter.

G

Graywacke. A type of sandstone marked by large grains of quartz and feldspar in a clay matrix. Commonly a gray color and containing small fragments of shale or slate.

Greenstone. An altered basic igneous rock of decided greenish color due to the presence of such minerals as chlorite, hornblende, and epidote.

Ground Water. Subsurface water occurring in the zone of saturation.

Gneissose. Having composite structure similar to gneiss, with alternating bands which differ in mineral composition and texture.

H

Hardpan. A hard impervious layer, composed chiefly of clay, cemented by relatively insoluble materials, does not become plastic when mixed with water, and limits the downward movement of water and roots. It differs from claypan.

Hydraulic Gradient. The change in static head per unit of distance in a given direction.

Hydrograph. A graph showing the changes in the water level in a well with respect to time.

Hydrologic Cycle. The complete cycle through which water passes, commencing as atmospheric water vapor, passing into liquid (rain) and solid (snow) as precipitation, thence along or into the ground surface, and finally again returning to the form of atmospheric water vapor by means of evaporation and transpiration.

Hydrology. The science that relates to the distribution and phenomena of naturally-occurring water.

Hydroxide. A compound containing the hydroxyl ion, OH^-, and one or more positive ions, e.g. ferrous hydroxide, $Fe(OH)_2$.

I

Igneous. Rock formed from the solidification of molten magma, either at depth or on the ground surface.

Insoluble. Incapable or very difficult in being dissolved in a liquid.

Intercalated. One body of material interbedded or interlaminated with another.

Interfinger. To grade or pass from one material to another through a series of interlocking or overlapping wedge-shaped layers.

Intrusive. Said of a rock that has solidified from magma below the ground surface.

Ion. An electrically charged atom or molecule, e.g. H^+, OH^-, etc.

L

Lagoonal. Of, or pertaining to a lagoon.

Lamprophyre. A dark, fine-grained dike rock in which dark minerals, such as biotite, hornblende, and pyroxene occur both as crystals and in the matrix.

Lava. Fluid rock such as that which issues from a volcano; also the same material solidified by cooling.

Lignite. A brownish-black coal in which the alteration of vegetal material has proceeded farther than in peat but not so far as bituminous coal.

Limestone. A bedded sedimentary rock consisting chiefly of calcium carbonate.

Limonite. Brown hydrous iron oxide (ferrous oxide).

Losing Stream. A stream which contributes recharge to the ground water body.

M

Mafic. Basic; applies to dark minerals such as hornblende, etc.

Magma. Naturally occurring fluid rock material, generated within the earth and capable of intrusion and extrusion, and from which igneous rocks form by solidification.

Manganous. Bivalent manganese, Mn^{++}.

Manganic. Trivalent manganese, Mn^{+++}.

Mathematical Model. A computer technique which simulates dynamic responses of a ground water basin to changes in recharge and pumping patterns. Used as a tool to predict future water levels.

Metabasalt. Metamorphosed basalt.

Metagraywacke. A graywacke that has undergone a slight degree of metamorphism.

Metamorphic. Rock which has formed in the solid state in response to pronounced changes of temperature, pressure, and/or chemical environment and which takes place below the ground surface. A metamorphic rock originally was of a different form, i.e. it originally was igneous, sedimentary, etc.

Micromho. The standard unit of specific conductance.

N

Mineral. 1. A naturally-occurring chemical compound which forms rocks. Minerals usually, but not always, have definite crystal structure. 2. A chemical constituent of water, such as sodium, chloride, iron, etc.

Monitoring Well. A well used for the periodic measurement of water levels and/or periodic sampling for water quality analyses.

Mudstone. A clay rock which is not fissile.

Mutual Water Company. A corporation or association formed to deliver water to its members or stockholders at cost and not for profit. It is not obliged to serve water to any but its own members or stockholders, and it is not under the jurisdiction of the Public Utilities Commission.

Nitrate. An ion containing the completely oxidized form of nitrogen, i.e. NO_3^-. Nitrogen in the nitrate ion has the form of N^{5+}.

Nitrite. An ion containing the partially oxidized form of nitrogen, i.e. NO_2^-. Nitrogen in nitrite ion has the form of N^{+++}.

Nodular. Having the shape of or composed of nodules.

Nodule. A small more or less rounded body generally somewhat harder than the enclosing sediment or rock matrix.

Nonwater-Bearing. Any geologic formation which normally does not yield supplies of ground water to wells in quantities sufficient for most beneficial uses. Nonwater-bearing rocks yield one or both of the following: (1) Meager supplies of water sufficient only for limited domestic use; (2) Unpotable water.

O

Obsidian. Volcanic glass.

Ooze. A fine-grained marine deposit which contains more than 30% of material of organic origin.

Orogeny. The process of forming mountains, particularly by folding and faulting.

Oxidation. 1. The process of combining with oxygen. 2. Increasing the electrical charge of an ion or atom in the positive direction. (See also Reduction.)

Oxide. 1. The final product of oxidation. 2. A compound of oxygen and one or more positive ions.

P

Peat. A dark brown to black material produced by the partial decomposition of plants.

Pebble. A smooth rounded stone ranging from 2 to 64 mm. in diameter.

Pegmatite. Coarse-grained igneous rocks occurring as dikes that cut across igneous rocks of finer grain size.

Pelecypod. A mollusc such as the clam.

Perched. Said of ground water that is separated from the underlying main ground water body by a zone of unsaturated materials. A perched ground water body has its own water table separate from that of the underlying ground water body.

Peridotite. A general term for essentially non-feldspathic intrusive, igneous rocks consisting of the mineral olivine, with or without other minerals such as amphibole and pyroxene.

Perlite. A volcanic glass having numerous concentric cracks.

Permeability. The ability of a geologic material to transmit fluids such as water. The degree of permeability depends on the size and shape of the pore space and the extent, size, and shape of their interconnections.

Physiography. The study of the physical features (landforms) of the earth. Includes physical geography and physical geology.

Piezometric Surface. Synonymous with potentiometric surface.

Pillow Structure. The peculiar form exhibited by some basic lavas which consist of a sequence of rounded masses that resemble pillows or filled sacks. The rounded masses fit closely upon one another. Pillow structure is generally believed to be the result of a submarine eruption.

Plagioclase. A series of rock-forming minerals belonging to the feldspar group.

Porosity. The ratio of the total volume of the pores in a rock or soil to its total volume; expressed as a percent.

Porphyry. An igneous rock in which larger crystals are set in a finer ground mass which may be crystalline, glassy, or both.

Potentiometric Surface. The imaginary surface to which water will rise in a well tapping a given aquifer. The potentiometric surface may be above ground; in this case, the well would flow. The water table is the potentiometric surface in an unconfined aquifer.

Precipitate. 1. To separate or become separated from a liquid. 2. The substance in a state separated from a liquid as a consequence of some chemical or physical change.

Precipitation. Rain, snow, mist, etc.; also the quantity of water so deposited on the earth.

Primary Opening. Openings or voids existing when the rock was formed. In sedimentary rock, primary openings are usually the result of the arrangement and nature of the original sediment.

Pumice. Solidifed volcanic froth; it is very light in density and will float on water.

Pumpage. The total amount of water pumped by wells from a ground water body.

Pyroclastic. A rock consisting of a mixture of solid material of all sizes ejected from a volcanic vent.

Pyroxene. A group of dark-colored rock-forming minerals.

Q

Quartz. A basic rock-forming mineral; crystalline silica dioxide.

Quartz Diorite. An intrusive igneous rock similar to diorite with the addition of quartz.

R

Reduction. 1. The process of removing oxygen. 2. Increasing the electrical charge of an ion or atom in the negative direction. (See also Oxidation.)

Regression. Gradual contraction of a shallow sea resulting in emergence of land as when sea level falls or land rises.

Rhyolite. A fine-grained to porphyritic extrusive igneous rock of the same mineral composition as granite.

S

Salt. Any of a class of compounds formed when the hydrogen of an acid has been replaced by a metal, as ferrous sulfate ($FeSO_4$) is an iron salt of sulfuric acid (H_2SO_4).

Safe Yield. 1. The annual amount of water that can be withdrawn from a ground water basin without producing any undesired result. A draft in excess of safe yield is termed overdraft. 2. The rate at which water can be withdrawn from an aquifer without depleting the supply to such an extent that withdrawal at this rate is no longer economically feasible.

Sanitary Seal. The cement grout envelope in the annular space between the well casing and the wall of the hole to ensure that no surface water can enter the well.

Schist. A medium or coarse-grained metamorphic rock in which the rock splits into thin, irregular plates. Mica is the dominant mineral.

Scoria. Volcanic slag. Volcanic material, usually of basaltic composition, characterized by dark color, vesicles, and heaviness. Includes cinders.

Sedimentary. Said of rocks formed from sediments. Includes such rock types as sandstone, conglomerate, shale, etc.

Serpentine. A rock which is the alteration product of several types of ultrabasic rocks.

Serpentize. The conversion of ultrabasic rocks to serpentine.

Shearing. The deformation of rocks by the cumulation of small lateral movements along inumerable parallel planes, resulting from pressure.

Silica Carbonate Rock. An altered form of serpentine; an extremely hard rock which ranges from green to brown and contains quartz and other silica minerals as well as a variety of carbonate minerals.

Sill. A relatively thin body of intrusive igneous rock that has been emplaced parallel to the structure or bedding of the adjacent rocks.

Siltstone. A very fine-grained rock composed predominantly of particles of silt size (1/16 to 1/256 mm. in diameter).

Specific Capacity. The discharge of a water well expressed as rate of yield per unit of drawdown.

Specific Conductance. The measure of the ability of a fluid to conduct an electrical current. Because conductance is the reciprocal of resistivity, the unit of conductance is reported as the reciprocal of the ohm, called the "mho".

Specific Yield. As applied to a rock or soil unit, it is the ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume. This ratio is expressed as a percentage.

Spilite. A type of basalt.

Static Head. The height to which a column of water will rise in response to pressure at a given point.

Static Level. The minimum depth to water in a nonpumping well.

Subsidence. The sinking, or lowering, of a part of the earth's crust.

Syncline. A fold in rocks in which the strata dip inward from both sides toward the axis.

T

Tectonic. Of, or pertaining to the forces of deformation of the earth's crust.

Transgression. Gradual expansion of a shallow sea resulting in the progressive submergence of land as when sea level rises or land subsides.

Total Dissolved Solids. The sum of the principal ions in a water quality analysis. A measure of the total mineralization of water.

Transmissivity. The rate of flow of water through each vertical strip of aquifer one foot wide having a height equal to the thickness of the aquifer and under a unit hydraulic gradient.

Transpiration. The process by which water vapor escapes from a living plant and enters the atmosphere.

Trivalent. An ion with a triple electrical charge, e.g. Fe^{+++}.

Tuff. A rock composed of compacted volcanic fragments smaller than 4 mm. in diameter.

Tuff Breccia. A volcanic breccia in which the matrix, composed of tuff, accounts for from 25 to 75 percent of the total volume.

U

Ultrabasic. Dark-colored igneous rocks which contain no quartz or feldspar.

Ultramafic. Ultrabasic.

Unconfined. 1. Water in an aquifer that has a water table. 2. An aquifer containing unconfined ground water.

Unconformity. A surface of erosion that separates younger strata from older rocks.

Unpotable Water. Water that is not fit for human consumption.

V

Vesicle. A small cavity in a volcanic rock formed by the expansion of a bubble of gas or steam during solidification of the rock.

W

Water-Bearing. Any geologic formation which normally yields supplies of potable ground water to wells in quantities sufficient for most beneficial uses.

Water Quality. The study and identification of the various constituents in naturally-occurring ground and surface water.

Water Table. 1. The upper surface of a zone of saturation except where that zone is confined by an impermeable stratum. 2. The locus of points in soil water at which the pressure is equal to atmospheric pressure. 3. The level at which water stands in a well that penetrates a ground water body just far enough to hold standing water.

Welded Tuff. A tuff which has been transformed into a very hard dense rock by the action of heat contained in the particles and in the enveloping hot gases.

Z

Zeolite. A group of minerals characterized by their easy and reversible loss of water of hydration and their significant capacity for ion-exchange.

Zone of Aeration. The zone between the land surface and the deepest water table. It includes the capillary fringe.

Zone of Saturation. That part of the earth's crust below the deepest water table in which all voids are filled with water.

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APPENDIX C

ENGLISH - METRIC EQUIVALENTS

Each unit with its abbreviation is followed by its equivalent in one or other units of the same quantity. In the text, the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

Length	Inch (in) - 2.54 centimeter (cm) Centimeter (cm) - 0.3937 inch (in) Foot (ft) - 0.3048 meter (m) Meter (m) - 3.2808 feet (ft); 39.37 inches (in) Mile (mi) - 1.6094 kilometer (km) Kilometer (km) - 0.6214 mile (mi)
Area	Acre (a) - 43,560 square feet (ft^2); 0.4047 hectare (ha) Hectare (ha) - 10,000 square meters (m^2); 2.471 acres (a) Square mile (mi^2) - 640 acres (a); 259 hectares (ha); 2.59 square kilometers (km^2) Square kilometer (km^2) - 100 hectares (ha); 0.384 square mile (mi^2) Square foot (ft^2) - 0.0929 square meter (m^2) Square meter (m^2) - 10.764 square feet (ft^2)
Volume	Gallon (gal) - 3.7853 liters (l); 0.00378 cubic meter (m^3) Liter (l) - 0.2642 gallon (gal); 1.057 quarts (qt) Cubic meter (m^3) - 264.173 gallons (gal); 1,000 liters (l)
Discharge	Gallon per minute (gpm) - 3.79 liters per minute (l/m) Liter per minute (l/m) - 0.264 gallon per minute (gpm) Gallon per minute per foot of drawdown (gpm/ft) - 0.21 liter per minute per meter of drawdown (lpm/m) Liter per minute per meter of drawdown (lpm/m) - 4.92 gallons per minute per foot of drawdown (gpm/ft) Million gallons per day (MGD) - 3780 cubic meters per day (m^3/d)
Ground Water Storage	Acre-foot (ac-ft) - 1,233.5 cubic meters (m^3) Thousand acre-feet (ac-ft) - 1,233,500 cubic meters (m^3); 1.23 cubic hectometers (hm^3) Cubic hectometer (hm^3) - Million cubic meters (m^3); 810.71 acre-feet (ac-ft)
Percolation	Minute per inch (mpi) - 0.39 minute per centimeter (m/cm) Minute per centimeter (m/cm) - 2.54 minutes per inch (mpi)
Concentration	Milligram per liter (mg/l) - 1 part per million (ppm)
Temperature	Degrees Celsius (°C) - 0.555 [Degrees Fahrenheit (°F) - 32] Degrees Fahrenheit (°F) - 1.8 [Degrees Celsius (°C)] + 32

APPENDIX D

GROUND WATER GEOLOGY

A summary of the ground water geology of Sonoma County along with a discussion of the basic principles of geology and hydrology were presented in Chapter II of this bulletin. Contained in this appendix is a detailed discussion of the geologic features of the county as they pertain to ground water. Included is information on the geologic history; the physical, water-quality, and water-yielding characteristics of the various nonwater-bearing and water-bearing formations; and the effect of geologic structures on the movement and quality of ground water.

Geologic History

The oldest rocks exposed in Sonoma County occur at Bodega Head, west of the San Andreas Fault. The granitic rocks found here represent the core of an ancient landmass that once stretched southward and included what is now the Point Reyes Peninsula, the Farallon Islands, and the granitic mountains of Santa Cruz and Monterey Counties. These intrusive rocks were formed at great depth when they crystallized during the early part of the Jurassic Period. Subsequent uplift brought them to the surface, and erosion has reduced them to the isolated remnants seen today.

East of the San Andreas Fault are found somewhat contemporaneous marine sediments, which were formed as geosynclinal deposits in an oceanic environment during the Jurassic Period. These deposits, which together comprise the Franciscan Formation and the Great Valley Sequence, are formed of sediments derived from an area located west of the present shoreline. The area which received these sediments was of broad extent and was slowly subsiding.

During the 50 million years that the sediments were being deposited, they were intruded with basic and ultrabasic rocks in the form of dikes, sills, and pillow lava flows, most of which subsequently have been completely serpentinized. During the Createaceous Period, deposition was halted and was followed by a brief period of uplift. During this uplift, coarse conglomeritic detritus was deposited in certain areas, while in others, sand and clay continued to mantle the sea bottom. In a few areas, notably along what is now the present sea coast, basaltic flows poured out from localized volcanic centers.

In the early part of the Tertiary Period, marine deposition again was the rule. Paleocene and Eocene sediments, ranging from sand to clay, were deposited in areas to the west and east of the San Andreas Fault. During Miocene time, the sea invaded the area, and shales and sands of the Neroly and related formations were deposited. Also in Miocene time, there were several periods of transgression and regression of the sea as the land surface oscillated above and below sea level. Toward the close of the Miocene Epoch, crustal compressional forces began forming the Coast Ranges.

Beginning in the early part of the Pliocene Epoch, a volcanic sequence was deposited in the south-central part of the county. After a subsequent period of erosion, deposition began anew, forming the sediments which now constitute the Petaluma Formation. The depositional environment of the Petaluma Formation consisted of shallow to brackish water embayments which had been eroded into the landscape formed from the Jura-Cretaceous and later rocks. Following deposition of the Petaluma beds, a period of orogeny occurred, which tilted, folded, and uplifted these beds while still young. This caused a widespread period of vigorous erosion, during which much of the then-soft Petaluma sediments were stripped off. By that time, much of eastern Sonoma County was above sea level, and here and there were lakes filled with water, which supported large communities of diatoms. At about this same time, movement began along the Tolay Fault, which caused a displacement of several thousand feet of formerly adjacent sediments.

During the latter part of the Pliocene Epoch, volcanic activity broke out in the eastern part of the county. Vents spewed out vast amounts of tuff-breccia, lava, ash, and cinders, all of which now constitute the Sonoma Volcanics. Meanwhile, to the west, in a shallow marine environment, sands and clays were being deposited to form the Merced Formation. This latter formation was deposited in an embayment that covered the central part of the county as far north as Healdsburg. At the close of the Sonoma volcanic episode, reworked volcanic detritus began to be deposited under lagoonal and deltaic conditions; these sediments now are the Glen Ellen Formation. Sediments in the lower part of the Glen Ellen Formation were deposited contemporaneously with those of the Merced Formation as shown by the interfingering of these two formations.

In the northwestern part of the county there was a broad, shallow depression with a northwesterly orientation. Deposition of sandy material in this depression occurred contemporaneously with Merced-Glen Ellen deposition farther south; sediments in this depression now comprise the Ohlson Ranch Formation. Subsequent uplift of this basin brought the Ohlson Ranch Formation to the elevation of the ridgetops where much of it was removed by erosion, leaving only the remnants seen today.

Uplift of the Ohlson Ranch sediments occurred at about the same time as uplift and faulting of the Merced and Glen Ellen sediments. By the close of the Pliocene Epoch, the Kenwood and other synclines had been formed, and the structural feature that now is Sonoma Valley began to take shape. To the west, however, were still rolling hills leading down to the sea, and no evidence of the Santa Rosa Plain as yet could be seen.

During the Pleistocene Epoch, uplift and erosion continued, with much of the Ohlson Ranch, Merced, and Glen Ellen Formations being stripped off. Present drainage courses were established and Older Alluvium was deposited in many areas. Downwarping along the Windsor Syncline in the Santa Rosa Plain area caused the creation of a broad valley which sloped southward from Dry Creek all the way to what is now San Pablo Bay.

In the late part of the Pleistocene Epoch, sea level stood some 300 feet (91 m) lower than it does today. Streams draining the highlands cut deep valleys as they meandered southward toward the Golden Gate. Local uplift in the vicinity of the Washoe Anticline subsequently created a gentle arch in the vicinity of Penngrove. This formed the present drainage patterns and turned the Russian River westward to the sea. Since the beginning of the Holocene Epoch, Mark West Creek has changed its course slightly. This event has been coupled with rapid aggradation along the creek and minor subsidence along Laguna de Santa Rosa to the south, all of which helped to create the swamp and marsh condition found today along Laguna de Santa Rosa from near Sebastopol downstream toward Occidental Road.

Geologic Formations and Their Water-Bearing Properties

Nearly all geologic formations in Sonoma County yield some degree of water to wells. Well yields range from 1,000 gpm (3,780 l/m) in wells completed in coarse-grained Holocene deposits, to less than 1 gpm (3.78 l/m) in wells in the Jura-Cretaceous and Tertiary marine sediments. In general, the Jura-Cretaceous and Tertiary marine sediments, along with the granitic rocks and serpentine, yield less than 5 gpm (19 l/m). Mineral constituents, such as chloride, iron, manganese, and boron may be present in sufficient amounts to make ground water nonusable. In contrast, the Pliocene to Holocene materials are the principal water producers in the county; the water derived from these materials usually is of good to excellent quality, although some water quality problems also may be present.

Each of the various geologic formations occurring in Sonoma County is discussed below. Included in the discussion is a description of its general lithology, its water-yielding characteristics, and the general character of ground water produced.

Granitic Rocks

An area of intrusive granitic rocks is exposed along the western side of Bodega Head. Named the Bodega diorite by Johnson (1943), the rocks consist of deeply weathered, sheared, and faulted hornblende-biotitie-quartz diorite. Pegmatite, aplite, and lamprophyre dikes occasionally are present; some of the rock mass exhibits gneissose banding. Johnson correlated the Bodega diorite with similar rocks occurring in the Santa Lucia and Gabilan ranges to the south; it is considered to be of pre-Franciscan age.

A spring-fed pond is located at the abandoned site of the Bodega Nuclear Power Plant. The pond is formed from ground water entering the foundation excavation area. The water level in the pond stands about 20 feet (6 meters) above sea level, and there is a constant outflow from the pond into Bodega Bay of from 10 to 20 gpm (38 to 76 l/m). The water in this pond is an acceptable quality sodium chloride water.

There are no known wells in the granitic rocks of Bodega Head. Wells drilled into this rock mass may be able to produce limited quantities of potable ground water from fractures, shears, and deeply weathered zones.

Franciscan Formation and Great Valley Sequence, Undifferentiated

General Character. Much of the mountainous area in the northwestern and northeastern parts of the county is underlain by an assemblage of marine sediments with a stratigraphic thickness of at least 40,000 feet (12,000 meters) that has been identified as part of the Franciscan Formation and the Great Valley Sequence. Lesser exposures of these rocks also occur in the southwestern and southeastern parts of the county.

In the north coastal area, west of the San Andreas Fault, the rocks of this group have been identified by Huffman (1972) as being of Cretaceous age and have been named the Stewarts Point Strata and the Anchor Bay Strata. These rocks are massive sandstone, conglomerate, and mudstone, all of marine origin. Underlying the Stewarts Point Strata near Black Point is a complexly faulted mass of spilitic basalt.

The rocks east of the San Andreas Fault have been divided into two main groups, the Franciscan Formation and the Great Valley Sequence. Rocks of the Franciscan Formation predominate throughout most of the area. These rocks are of Jura-Cretaceous age and consist of three main rock types. The sedimentary sequence consists of interbedded graywacke and shale with minor amounts of greenstone, conglomerate, chert, and limestone. Much of the rock is highly shattered and commonly is veined with zeiolite minerals. The metamorphic sequence contains metagraywacke with lesser amounts of weakly metamorphosed greenstone and chert; some glaucophane schist also is present.

The sheared sequence includes sheared sandstone and shale with discrete masses of serpentine and other rock types such as ultramafic, silicacarbonate rock, chert, greenstone, pillow lava, metabasalt, glaucophane schist, eclogite, and amphibolite. All of these rock types are intensely folded and faulted; zones of shearing and crushing are common. Rocks of the Great Valley Sequence are composed of well-bedded sandstone, shale, siltstone, and conglomerate. Included near the base of the Great Valley Sequence are masses of pillow lava, basalt breccia, diabase, gabbro, quartz diorite, and ultramafic rocks.

Water Quality. Only meager data are available on the quality of ground water contained in the fracture and shear zones of the Franciscan Formation and Great Valley Sequence. Excellent quality water is found at a number of cold springs which issue from these rocks. Thermal areas, such as The Geysers and Skaggs Springs, yield hot to boiling water with compositions ranging from highly mineralized sodium bicarbonate water to unpotable magnesium sulfate and ammonium sulfate water.

Water quality data are available for only one well tapping the rocks of the Franciscan Formation. This well Number 4N/7W-8R80, is located south of Petaluma and is 854 feet (260 meters) deep. The well produces an excellent quality sodium bicarbonate water that has a total hardness of only 5 mg/l. The water is used for both domestic purposes and dairy operations.

Well Yield. Ground water is present in the Franciscan and Great Valley Sequence rocks as indicated by the great number of springs in the areas of outcrop (see Figure 18). Ground water is not present in primary openings, as with the water-bearing materials, but rather in secondary openings such as joints, fractures, and shear zones. Wells drilled in these rocks frequently are completed as "hard rock" wells; that is, they usually are uncased. Well yields generally are low and range from less than 1 to at most 3 gpm (<4 to 12 l/m). These meager yields, however, may be sufficient for domestic purposes provided that water storage facilities of at least 1,000 gallons (3.78 (m^3) are available.

Well log data are available from 27 wells drilled into the Jura-Cretaceous rocks. These wells range in depth from 20 to 257 feet (6 to 78 meters); the range of yield of water is from 0.2 to

68 gpm (0.7 to 257 l/m), with the average being 18.4 gpm (70 l/m). Static water levels ranged from 2 feet to 160 feet (0.6 to 48.7 meters); one well was reported as flowing. An indication of the ability of a "hard rock" well to yield water is its discharge per unit of saturated rock. For wells in the Jura-Cretaceous rocks, this value ranged from 0.01 to 1.5 gpm per foot (0.1 to 18 l/m per meter); the average was 0.22 gpm per foot (2.7 l/m per meter).

Serpentine

Elongate masses of serpentine and related ultramafic rocks occur within the outcrop area of the Franciscan Formation. Major areas of this rock type have been identified on Plate 1. The rock areas so identified consist of blocks of greenish-black serpentinized periodotite enclosed in a bluish-green matrix of sheared serpentine. The weathered surface of these masses commonly is reddish-brown due to concentrations of iron oxides. Serpentine is not usually considered a reliable source of potable ground water. Mineral analyses are available from two springs in an area of serpentine (see Table 15). One spring yields a highly alkaline unpotable calcium hydroxide water; the other yields a magnesium bicarbonate water of acceptable potability.

Dry Creek Conglomerate

General Character. Although usually mapped as part of the Great Valley Sequence, the Dry Creek Conglomerate is considered a separate unit for ground water studies because of its ability to transmit and yield appreciable quantities of good-quality ground water to wells. The conglomerate is situated in the fold of the Geyserville Syncline which trends northwesterly from east of Fitch Mountain through Lytton to Pritchett Peaks, a distance of about 18 miles (29 kilometers). The surface exposure of the conglomerate ranges from one to two miles (1.6 to 3.2 kilometers) in width. The conglomerate consists of beds up to 100 feet (30 meters) thick of well-rounded cobbles and boulders of granodiorite, porphyry, chert, quartz, and greenstone; the matrix is an arkosic sandstone. The conglomerate is extremely massive; Gealey (1950 estimated its thickness at 5,000 feet (1,500 meters). Exposures of a similar conglomerate have been reported to the southeast in Napa County.

Water Quality. Ground water in the Dry Creek conglomerate is an excellent quality calcium bicarbonate water. Table 2 presents a summary of the quality characteristics of ground water in the Dry Creek conglomerate. No data have been gathered concerning the presence of any deleterious mineral constituents in ground water in this conglomerate.

Well Yield. Wells in the Dry Creek Conglomerate yield sufficient water for most domestic purposes. Data are available for 11 wells tapping this conglomerate. The wells, situated mostly near the intersection of Canyon Road and Walling Road, range in depth from 50 to 341 feet (15 to 104 meters). After completion, depths to standing water ranged from 22 feet (6.7 meters) in a 50-foot (15-meter) well to 145 feet (44 meters) in the 341-foot (104-meter) well. All wells were tested by the well driller with a bailer; reported yields ranged from 20 to 60 gpm (76 to 227 l/m) with drawdowns ranging from 15 to 105 feet (4.5 to 32 meters).

Tertiary Marine Sediments

General Character. Two areas of Tertiary marine sediments occur in Sonoma County. West of the San Andreas Fault, near Fort Ross and south of the Gualala River, marine sediments of early Tertiary age are exposed. These sediments overlie Cretaceous sediments and have been identified by Blake, et al, (1971) as two distinct units. Paleocene to middle Eocene strata near Fort Ross have been called the Strata of German Rancho; these rocks consist of thin to thick interbeds of sandstone and mudstone. Near the Gualala River, Miocene marine sediments, consisting of mudstone, siltstone, and glauconitic sandstone, have been tentatively classed by Huffman (1972) as being part of the Gallaway Formation. Associated with these latter beds are two small areas of basalt.

In the upper part of Nuns Canyon, near the eastern border of Sonoma County, Weaver (1949) described an exposure of Tertiary marine sediments and assigned them to the Neroly Formation. The beds are of Miocene age and are composed principally of northwesterly dipping medium grained tan sandstone containing casts of marine pelecypods.

Water Quality. Ground water in the Tertiary marine sediments along the coast is a moderately hard calcium bicarbonate water suitable for most domestic purposes. There are no water quality data available from the Tertiary marine sediments of the Nuns Canyon area.

Well Yield. Yield data are available from eight wells drilled into the Tertiary marine sediments north of Fort Bragg; no wells have been drilled in the Tertiary marine sediments of the Nuns Canyon area.

Yields from the wells along the coast range from a low of 0.2 gpm (0.4 l/m) to a high of 37 gpm (140 l/m); the median yield is 5.5 gpm (21 l/m). Static water levels range in depth from 7 to 33 feet (2 to 13 meters) and average 22 feet (6.7 meters). Using the criteria of well yield per foot of saturated thickness, the average value for the Tertiary rocks is 0.104 gpm per foot (1.3 l/m per meter) of saturated thickness; the range is from 0.001 to 0.33 gpm per foot (0.01 to 4 l/m per meter).

Petaluma Formation

General Character. The Petaluma Formation is exposed at various localities in Sonoma County, from Sears Point northward nearly to Santa Rosa. The formation consists of folded continental and brackish water deposits of clay, shale, sandstone, with lesser amounts of conglomerate and nodular limestone; occasional thick beds of diatomite are present. Work done by Dickerson (1922) indicates that the formation is of upper Miocene age. According to Morse and Bailey (1935), the Petaluma Formation is more than 4,000 feet (1,220 meters) in stratigraphic thickness. Weaver (1949) measured a section of the formation near Lakeville and found a total thickness of 1,059 feet (323 meters). The section contained 70 percent clay shale, 25 percent sandstone, and 5 percent pebbly conglomerate. A 94-foot (29-meter) thick section was measured by Cardwell (1958) near Waugh School on Corona Road. Medium-grained, thinly cross-bedded, friable sandstone accounted for 48 percent of the total. The remainder was silty clay with large nodules of limestone.

The area of exposure of the Petaluma Formation from the vicinity of Lakeville southeast to Sears Point has long been stratigraphically indefinite. Morse and Bailey (1935) originally mapped these beds as the "Petaluma Beds" and assigned them to the Pliocene, on the basis of ostracod fossils and leaf impressions. Subsequent work by Weaver (1949) and Cardwell (1958), placed these beds in the younger Merced Formation. Fox, et al (1973), Sims, et al (1973), and Blake, et al (1974) remapped much of this area and placed these sediments again in the Petaluma Formation. In the current investigation, the Petaluma Formation has been defined as being contemporaneous in part with the Merced Formation.

The upper part of the Petaluma Formation apparently interfingers with sediments of the Merced Formation, thus causing some of the confusion in identifying areas of the Petaluma Formation. Logs of water wells analyzed during this current investigation indicated that a number of wells east of the Denman Flat area reported "blue sandstone with shells" in areas previously identified as Petaluma Formation. Because fossiliferous sandstone is diagnostic of the Merced Formation, these areas have been assigned to that latter formation.

Water Quality. Ground water in the Petaluma Formation ranges from sodium bicarbonate to sodium chloride and calcium chloride in composition. Water analyses indicate that wells in the area of outcrop will yield water with a range of electrical conductivity from 840 to 1,400 micromhos; chloride ion ranges from 78 to 177 mg/l. Deep wells underlying Petaluma Valley tap beds of the Petaluma Formation. Here, wells yield a calcium-chloride water; electrical conductivities are 800 to 900 micromhos and chloride contents are 175 to 200 mg/l. In all cases, boron concentrations are 0.2 mg/l or less.

Well Yield. The Petaluma Formation is noted for its low well yield. Bailer test data are available from 42 wells tapping the formation. These wells yielded from as low as 5 gpm (19 l/m) to as much as 300 gpm (1,134 l/m). Drawdowns were reported to be as much as 200 feet (61 meters) at one well which yielded only 10 gpm (38 l/m). One 739-foot (225-meter) well in the Bennett Valley area penetrates the Petaluma Formation; the results of a 72-hour pump test are available for this well. Using the method developed by Brown (1963) and utilized in the study of the ground water resources of Livermore Valley, Ford and Hills (1974), a transmissivity of 3,754 gpd/ft (46.54 m^3/day) was derived for the Petaluma Formation.

Sonoma Volcanics

General Character. The Sonoma Volcanics were named by Weaver (1949) for a thick sequence of volcanic ejecta and related volcanic sediments that are exposed in the Sonoma Mountains. Weaver identified related volcanic materials, also assigned to the Sonoma Volcanics, occurring in the Mayacmas Mountains and the mountains separating Sonoma Valley from Napa Valley. Cardwell (1958) extended the volcanic sequence to include isolated volcanic exposures to the west of the Santa Rosa Plain.

Included with the Sonoma Volcanics, but differentiated on Plate 1, is a sequence of volcanic sediments which have been differentiated by Fox, et al (1973). Also differentiated on Plate 1 are exposures of the St. Helena Rhyolite, which first was described by Osmont (1905) and further identified by Weaver (1949). In the area of Healdsburg and Alexander Valley much of the area now shown as Sonoma Volcanics originally was considered as the Sonoma Group by Gealey (1951). Later work by Blake, et al (1971) placed these materials within the Sonoma

Volcanics. Exposures of the Sonoma Volcanics in the northeastern corner of the county have been identified by McLaughlin (1974) as the Caldwell Pines Basalt and the Cobb Mountain Rhyolites.

The Sonoma Volcanics comprise a great thickness of mixed volcanic materials consisting of flows, dikes, plugs, and beds of andesite, rhyolite, basalt, tuff breccia, agglomerate, tuff, and related intermediate to acidic flow rocks. Banded flows of welded tuff, perlite, and obsidian occur locally. Some obsidian zones are up to 10 feet (3 meters) in thickness and range from glassy to prophyritic. Volcanic ejecta comprise some 60 percent of the total mass, with the remainder being composed of a variety of volcanic-related sediments such as black volcanic sandstone, ashy clay, tuffaceous sandstone, and diatomite. It is this latter, the diatomite, which allowed for the dating of a part of the Sonoma Volcanics. Axelrod (1944) studied samples of the Sonoma diatomite and identified it as being middle to late Pliocene in age, on the basis of plant fossils contained therein.

The Sonoma Volcanics accumulated in a basin that was some 30 miles (48 kilometers) wide in an east-west direction and 40 miles (64 kilometers) long from north to south. With a maximum thickness of well over 1,000 feet (300 meters), the volcanics cover an area of about 350 square miles (91 square kilometers). The volcanics usually overlie the older Jura-Cretaceous sediments with a pronounced unconformity. Certain parts of the volcanics interfinger with partly contemporaneous beds of the Petaluma, Merced, and Glen Ellen Formations. In some areas the volcanics unconformably overlie or are in fault contact with the Petaluma Formation.

Lower portions of the Sonoma Volcanics are strongly deformed as a result of intense folding and faulting. This condition and the extreme lateral variability of the flows make it nearly impossible to trace flows and beds over any great lateral distance. According to Huffman (1971), upper portions of the Sonoma Volcanics are but little deformed and occur as gently sloping flows of basalt and andesite.

In the Sonoma Valley area, Kunkel and Upson (1960) reported a great number of thick flows of tuff breccia containing blocks of andesite up to 4 feet (1.2 meters) across contained in a matrix of fine-grained ash. Also noted were locally abundant beds of red scoria having high permeability. In contrast to the andesitic nature of the Sonoma Volcanics found elsewhere, the volcanics in Alexander Valley are composed of basaltic flows and related material. Many of the basalt flows are up to 100 feet (30 meters) in thickness; pillow structure is common.

Water Quality. Ground water in the Sonoma Volcanics usually is a satisfactory quality sodium bicarbonate water. Boron concentrations of up to 1.0 mg/l have been reported. Because of a higher than usual geothermal gradient, some ground water from deep wells in the volcanics is warmer than that found at equal depth in other formations. The unusual gradient illustrated by the water from Well 7N/7W-32G1, which is 403 feet (123 meters) deep and produces water with a temperature of 74°F (23°C), a temperature somewhat warmer than that of usual ground water.

Well Yield. The productivity of water wells drilled into the Sonoma Volcanics is highly variable and unpredictable. In some areas a driller might complete a well producing adequate quantities of water for domestic use, while only a short distance away a nonproducer, or dry hole, had previously been drilled. In general, successful wells drilled into the volcanics should yield from 10 to 50 gpm (38 to 189 l/m) and drawdowns should be on the order of from 10 to 120 feet (3 to 37 meters). Because of the large expected drawdowns and the fact that standing water may be as deep as 200 to 300 feet (60 to 90 meters), domestic wells ranging in depth to 500 feet (150 meters) are not uncommon.

Three examples illustrate the nature of the Sonoma Volcanics as a water-producing unit. The first is a well on Mountain Home Ranch Road, near the Napa County line. The well originally was drilled to a depth of 200 feet (60 meters) in "yellow sandstone, blue sandstone, blue clay, shattered rock, and hard rock". When tested with a bailer, the well produced 20 gpm (76 l/m) with a drawdown from standing level of 25 feet (7.6 meters); standing water was at a depth of 40 feet (12 meters). These data indicate that the specific capacity of the well was 0.8 gpm per foot (9.9 l/m per meter) of drawdown. Six years after the well was completed, it was deepened to 400 feet (120 meters), passing through 200 feet (60 meters) of "black volcanic rock". The water level in the deepened well was 330 feet (100 meters) and when tested with a bailer, it produced 20 gpm (76 l/m) with a drawdown of 20 feet (6 meters); the specific capacity of the deepened well was 1.0 gpm per foot (12.4 l/m per meter) of drawdown.

A pair of wells also along Mountain Home Ranch Road illustrates the unpredictive nature of the Sonoma Volcanics. One well was drilled to a depth of 241 feet (73 meters) and was perforated from 220 to 240 feet (67 to 73 meters) in "black volcanic rock". When tested, this well yielded 50 gpm (189 l/m) with a drawdown of 5 feet (1.5 meters). The specific capacity of the well was 10.0 gpm per foot (124 l/m per meter) of drawdown, and the standing water level in this well was 180 feet (55 meters). A short distance away, another well was drilled to a depth of

256 feet (78 meters). The perforated interval in this latter well was 156 to 256 feet (48 to 78 meters) in "volcanic conglomerate". On test, the well produced 40 gpm (151 l/m) with a drawdown of 35 feet (11 meters); the specific capacity was 1.1 gpm per foot (13.6 l/m per meter) of drawdown. The depth to standing water in this well was reported to be 165 feet (50 meters).

Finding water in the Sonoma Volcanics is not always possible. This is illustrated by the records from four test wells drilled near St. Helena Road. The first test well was drilled one-quarter mile (0.4 km) from an existing well and went to a total depth of 841 feet (256 meters). The log indicated a succession of "hard blue rock, cemented gravel with volcanics, multi-colored rock, white volcanic ash with pebbles, and hard rock". When tested with a bailer, the well yielded but 2 gpm (7.6 l/m) with a reported drawdown of 650 feet (198 meters); the specific capacity was 0.004 gpm per foot (0.05 l/m per meter) of drawdown. Three other test wells then were drilled on the same property to depths of 270, 225, and 190 feet (82, 69, and 58 meters), all in sequences of "sandstone, broken rock, and blue clay". Being dry holes, all were abandoned.

The water-yielding characteristics of the Sonoma Volcanics in the area of the Sonoma Mountains is similar to that in the mountainous area to the east. A well was drilled at Jack London State Historical Monument to a depth of 136 feet (41 meters). The well log indicated "red rock, fractured gray basalt, and red and black clay". Tested for 24 hours, the well yielded 315 gpm (1,190 l/m) with a drawdown of 12 feet (3.6 meters); the depth to standing water was 28 feet (8.5 meters). The specific capacity of this well was 26.2 gpm per foot (324.9 l/m per meter) of drawdown. In contrast, a deep municipal well was drilled several miles to the south. This 1,005-foot (306-meter) well intercepted "black rock, multi-colored rock, black and red rock, green rock, and conglomerate". When tested, it yielded 60 gpm (227 l/m) with a drawdown of 720 feet (219 meters). The specific capacity was 0.075 gpm per foot (0.9 l/m per meter) of drawdown. Standing water in this well was at a depth of 80 feet (24 meters).

Ohlson Ranch Formation

General Character. The Ohlson Ranch Formation has been described by Higgins (1960) as consisting of marine sandstone, siltstone, and conglomerate up to 160 feet (49 meters) thick similar in appearance to the Merced Formation. The Ohlson Ranch Formation occurs only in the northwestern part of Sonoma County in the vicinity of the town of Annapolis. Here, resting atop ridges composed of dipping marine strata of the Franciscan Formation, flat-lying beds of Pliocene age fluvial sediments occur. Wave-cut terraces and sea stacks buried beneath the formation indicate that it was formed in a shallow-water embayment. Since deposition, the shallow basin has been uplifted and dissected by erosion, leaving the isolated areas as they are today. It is not known if the sediments of the Ohlson Ranch Formation are a northwest extension of the similar sediments of the Merced Formation to the south, but it is assumed that the two formations are contemporaneous.

Water Quality. Water quality data are available from two wells in the Annapolis area. These wells yield an excellent quality sodium bicarbonate water.

Well Yield. Well yield data are available from five wells tapping the Ohlson Ranch Formation in the vicinity of Annapolis. Yields from these wells range from 2 to 36 gpm (7.6 to 136 l/m), with drawdowns ranging from 30 to 125 feet (9 to 38 meters).

Merced Formation

General Character. The Merced Formation is one of the principal water-producing formations in Sonoma County. The formation consists of massive beds of fine to very fine-grained sandstone which is exposed over a broad area extending from Petaluma, on the south, to the Russian River, and from the west edge of the Santa Rosa Plain westward to beyond Occidental. Exposures of pebble conglomerate and siltstone in the area east of Cloverdale have also been included in the Merced Formation, although the exact stratigraphic relationship of this latter unit is not clear. In the subsurface, the Merced Formation has been identified at depth beneath the Santa Rosa Plain as well as beneath a cover of younger alluvium in Petaluma Valley.

The color of the Merced sandstone ranges from red, to orange, to white in exposed sections and from blue to gray in the subsurface where the beds have been under reducing conditions since deposition. Many well drillers report "clam shells" and "oysters" when drilling in the Merced Formation, indicating the wells have penetrated one of the numerous fossiliferous zones known to exist throughout the formation. Paleontological studies reported by Cardwell (1959) show that most shells belong to five reported species of pelecypods and four of gastropods. So abundant are many of the shell beds that they resemble coquina.

Much of the sandstone is loose and poorly cemented, although some beds, principally the more fossiliferous ones, are cemented to some degree with calcium carbonate and iron oxide. Near the base of the formation there is a bed of white tuffaceous material about 10 feet (3 meters) thick. This bed is exposed near the western edge of the outcrop area where it can be seen as white patches on the hillsides. Interbedded with the beds of the Merced Formation are several beds of tuff breccia, one of which attains a thickness of 10 feet (3 meters). Whether these tuff breccia flows represent distal ends of flows from the Sonoma Volcanics or whether they are from some local source is not known. Johnson (1934) found a volcanic neck northeast of Bodega and suggested that as a possible source. Travis (1952), however, stated that there is no evidence to support this view.

The Merced Formation is of late Pliocene age and was deposited in a subsiding embayment that was open to the ocean. Cardwell (1959) has postulated that the Merced sediments were derived from older Franciscan rocks to the north and were brought southward by a major trunk stream to be deposited in a lagoonal environment that was protected from the ocean by an off-shore bar. The sediments were deposited on a surface of high relief carved into the underlying Franciscan sediments. Occasional outliers of Franciscan rocks seen today surrounded by Merced sediments represent former islands that were partially buried during Merced sedimentation.

The Merced Formation has been estimated by Cardwell (1959) as being not over 2,000 feet (600 meters) thick; however, Travis (1952) estimated the total thickness of the Merced as being only 500 feet (150 meters). Well log data developed during the present study suggest that the Merced is at least 1,000 feet (300 meters) thick.

Water Quality. Ground water in the Merced Formation is of excellent quality and varies from calcium bicarbonate and magnesium bicarbonate to sodium bicarbonate in composition. Typical conductivities range from 140 to 420 micromhos. Wells tapping unoxidized (blue) sandstone may yield water containing excessive amounts of iron and manganese.

Well Yield. The Merced Formation produces large quantities of ground water. The specific yield of the formation ranges from 10 to 20 percent, an unusually high value. This high specific yield is due to the preponderance of even-grained sand found in wells to depths of over 400 feet (120 meters). Yields of wells tapping this formation frequently produce from 20 to 1,000 gpm (76 to 3,780 l/m); drawdowns are minimal, usually from 10 to 150 feet (3 to 45 meters). Domestic wells perforated for only a short distance produce adequate yields for household use, even if wells are located on adjacent lots and lot size is minimal. Deep wells, usually irrigation or municipal, typically are gravel-packed.

Specific capacities of wells, based on bailer tests, indicate that the Merced sands yield about 0.1 to 5.0 gpm per foot (1.2 to 62 l/m per meter) of drawdown. For example, one well drilled along Liberty Road west of Petaluma had a total depth of 163 feet (49 meters). Of this depth, 160 feet (48 meters) was logged as "yellow sand, blue sand, sandstone ledges, and streaks of shells". Tested with a bailer, the well yielded 30 gpm (113 l/m) with a drawdown of 110 feet (34 meters); the standing water level was at a depth of 40 feet (12 meters). These data indicate a specific capacity of 0.27 gpm per foot (3.3 l/m per meter) of drawdown. Farther north, a 385-foot (117-meter) domestic well was drilled on Baker Lane, near Sebastopol. The first 3 feet (0.9 meters) was reported to be "topsoil"; the remaining depth of the well was reported as "sand, yellow sandstone, and blue sandstone". Blank casing was installed in the well to a depth of 270 feet (82 meters). Tested with a bailer, the well produced 16 gpm (60 l/m), with a 30-foot (9-meter) drawdown. The depth to standing water was reported to be 50 feet (15 meters). These data indicate that the specific capacity of the well was 0.53 gpm per foot (6.6 l/m per meter) of drawdown.

Reported standing water levels ranged from 35 to 60 feet (11 to 18 meters). Statements from well owners in the area indicate that water levels decline markedly during the summer months and many wells go dry by early fall. On the basis of an approximate areal extent of 8,000 acres (3,200 hectares) and an average saturated thickness of 50 feet (15 meters), the Ohlson Ranch Formation has an estimated maximum storage capacity of about 25,000 acre-feet (30 hm^3). This total probably is significantly less when water levels have declined to their lowest levels.

Glen Ellen Formation

General Character. The Glen Ellen Formation is of Plio-Pleistocene age and was first described by Weaver (1949) from outcroppings of poorly sorted clays, sands, gravels, and cobbles occurring near Glen Ellen in the upper part of Sonoma Valley. Not always recognized as a separate formation, the Glen Ellen Formation also has been identified as the "Fresh-Water Merced" by Johnson (1934), the upper part of the "Sonoma Group" by Gealey (1951), and as "Older Alluvium" by Travis (1952). Later work by Cardwell (1958), Kunkel and Upson (1960), and Cardwell (1965) fully defined the formation and its mapped area to its present limit. Exposures of the Glen Ellen Formation, as now mapped, extend from near Sonoma, on the south, through the central part of the Santa Rosa Plain, to Alexander Valley and Dry Creek Valley on the north.

The Glen Ellen Formation is composed of an extremely heterogeneous mixture of pale buff clay, silt, sand, and gravel; some lignite has been noted. Many beds grade laterally from coarse gravels into clay. The coarse materials are usually of andesitic composition, although some obsidian is present. Particle size ranges up to 6 inches (15 centimeters) in diameter. Near the town of Glen Ellen, a section of the Glen Ellen Formation was measured by Cardwell (1958). The section had a total thickness of 68 feet (21 meters); 18 feet (5 meters) of section was composed of fine to coarse-grained cross-bedded sandstone and conglomerate, the remainder being siltstone with lenses of coarse sand and pebbles. Beds of coarse pebble conglomerate occur in the Rincon Valley area. These beds dip nearly virtically and are believed by Cardwell (1958) to cause artesian conditions in wells located in Township 7 North, Range 7 East, Sections 8 and 9.

The Glen Ellen Formation is up to 3,000 feet (900 meters) thick. It has been deposited in several parallel troughs as a deposit of coelescing piedmont and valley alluvial fans; some clayey portions were deposited in a lagoonal environment. Much of the Glen Ellen overlies the Sonoma Volcanics with some degree of unconformity. At a few localities it is intercalated with volcanic materials belonging to the Sonoma Volcanics. Likewise, much of the Glen Ellen is known to unconformably overlie sediments of the Merced Formation. Some beds of the continental Glen Ellen, however, are interfingered with beds of the marine Merced Formation. In a few areas, beds of the Glen Ellen directly overlie nonwater-bearing rocks of the Franciscan Group. In the lower Sonoma Valley area, the sediments of the Glen Ellen Formation are believed by Kunkel and Upson (1960) to grade laterally into beds of the contemporaneous Huichica Formation.

Water Quality. Ground water in the Glen Ellen Formation has a greater range of character than any other formation in Sonoma County. Some of the best and some of the poorest quality water is obtained from this formation. Wells generally 100 feet (30 meters) deep yield a magnesium-bicarbonate water of moderately good quality; unusually high content of nitrate ion may be present. Wells up to 800 feet (243 meters) in depth yield a moderately good quality sodium bicarbonate water. Very deep wells, such as those greater than 1,000 feet (300 meters), yield a poorer quality sodium bicarbonate water.

At scattered localities throughout the formation, boron concentrations of up to 1.0 mg/l have been reported, as has water containing over 90 percent sodium.

Well Yield. The Glen Ellen Formation is highly variable in its water-yielding capability. In the Santa Rosa Plain area, wells tapping this formation generally yield adequate supplies for domestic use, stock watering, or limited irrigation. Yields usually range from 15 to 30 gpm (57 to 113 l/m), with drawdowns of about 10 to 50 feet (3 to 15 meters). Specific capacities based on bailer tests range from 0.5 to 20.0 gpm per foot (6 to 248 l/m per meter) of drawdown.

The highly variable nature of the formation is indicated by yield data from two wells in Section 12, Township 7 North, Range 7 West. One well near Piner Road produced 40 gpm (151 l/m) with a 2-foot (0.6-meter) drawdown. The standing water level in this 102-foot (31-meter) well was reported to be 10 feet (3 meters). The well log indicated a total of 17 feet (5 meters) of "large gravel and sand", with the remainder being "sandy clay, blue clay, and gray clay".

A short distance west on Willowside Road, a well of 128-foot (39-meter) depth was drilled. On test, this well produced 20 gpm (76 l/m) with a 71-foot (22-meter) drawdown. The standing water level was 13 feet (3.9 meters). The log of the well indicated 3 feet (1 meter) of "brown sand with small gravel" with the remainder being "brown clay, blue clay, and blue sandy clay with gravel".

Near the town of Glen Ellen, the formation yields somewhat less water than in the Santa Rosa Plain. Here again, however, yields are unpredictable. For example, along Henno Road, a well was drilled to 380 feet (116 meters) in alternating zones of "cemented gravel, yellow clay, brown shale, and clay gravel". Tested with a bailer, the well produced 20 gpm (76 l/m), with a drawdown of 16 feet (4.8 meters); standing water was recorded at a depth of 49 feet (15 meters). Also along Henno Road, three more holes were drilled to 23, 97, and 150 feet (7, 30, and 46 meters); all were dry. On the same property, three more holes were drilled to 82, 200, and 322 feet (25, 61, and 98 meters). Each was tested and found to produce only 1 gpm (3.8 l/m); each was subsequently abandoned.

To the north, in Kenwood and Rincon Valleys, yields from the Glen Ellen Formation are not much better. One 280-foot (85-meter) well drilled on Fairway Court yielded only 30 gpm (113 l/m), with a drawdown of 210 feet (64 meters); standing water was at a depth of 30 feet (9 meters). The well log indicated that a successive sequence of clay and cemented gravels was intercepted. Most successful wells drilled in the Glen Ellen Formation in the Rincon Valley, Kenwood Valley, and Valley of the Moon areas tap the underlying, more prolific water-bearing materials of the Sonoma Volcanics.

A great thickness of Glen Ellen materials occurs in the Windsor area. Here, well yields range from 15 to 40 gpm (57 to 151 l/m) for most wells. Drawdowns are less than 50 feet (15 meters) with depths to water usually being less than 100 feet (30 meters). The highly variable nature of the water-yielding characteristics of the materials is illustrated by the productivity of two nearby gravel-packed wells in the vicinity of Piner Road and Gerhard Drive. One well is 122 feet (37 meters) deep and when tested with a bailer, yielded 30 gpm (113 l/m), with a 65-foot (20-meter) drawdown. Its specific capacity was 0.47 gpm per foot (5.8 l/m per meter) of drawdown. The well log indicated that the well penetrated a succession of blue clay, brown clay, and blue sandy clay, with streaks of gravel in the perforated interval. The other well is 102 feet (31 meters) deep and is perforated from 42 feet (12.8 meters) to bottom. The log indicates that in the perforated interval the well penetrated 49 feet (15 meters) of brown sandy clay, gray clay, and blue clay, and also 10 feet (3 meters) of large gravel and blue sand. Tested with a bailer, the well yielded 40 gpm (151 l/m, with a drawdown of 2 feet (0.6 meter). The specific capacity of this well is 20.0 gpm per foot (248 l/m per meter) of drawdown. Standing water in this well was reported as being 10 feet (3 meters).

Deeper wells in the Windsor area are capable of yielding upwards of 500 gpm (1,890 l/m), as shown by the log of a 400-foot (122-meter) well drilled near Hembree Lane. The well intercepted 78 feet (24 meters) of blue sand and gravel. A 72-hour pump test was made on the well, and it produced 500 gpm (1,890 l/m), with a drawdown of 72 feet (21.9 meters). The specific capacity was found to be 3.7 gpm per foot (45.8 l/m per meter) of drawdown.

The hills east of Windsor contain a number of areas where sediments of the Glen Ellen Formation are exposed. Wells here, such as along Calistoga Road and Chalk Hill Road, produce from 10 to over 100 gpm (38 to over 378 l/m), with drawdowns ranging from 10 to 200 feet (3 to 60 meters). Specific capacities range from 0.2 to 6.2 gpm per foot (2.5 to 76.9 l/m per meter) of drawdown. One well was drilled near Reible Road to a depth of 135 feet (41 meters). The well penetrated sandstone from a depth of 71 feet (22 meters) to bottom. It was reported that the well had an artesian flow of approximately 80 gpm (302 l/m) at the time of construction.

Well yields from the Glen Ellen Formation in the Alexander Valley area tend to be about the same as at wells tapping this formation in other areas. Yields range from 3 gpm (11 l/m) to over 30 gpm (113 l/m), with drawdowns from 20 to 85 feet (6 to 26 meters); specific capacities range from 0.05 to 1.5 gpm per foot (0.6 to 18.6 l/m per meter) of drawdown.

Along Lytton Springs Road, well yields from the Glen Ellen Formation are extremely variable. The lowest yield was from a 198-foot (60-meter) well, which produced 20 gpm (76 l/m), with a drawdown of 35 feet (11 meters); standing water was at

115 feet (35 meters), and the specific capacity was 0.57 gpm per foot (7.1 l/m per meter) of drawdown. In contrast, another well drilled along Lytton Springs Road went to only 76 feet (23 meters), of which the interval from 33 to 76 feet (10 to 23 meters) was reported to be "coarse cemented gravels, blue sandy clay, and cemented blue gravels with loose streaks". Tested with a bailer, the well produced 50 gpm (189 l/m) with a drawdown of only 1 foot (0.3 meter); the depth to standing water was reported as 27 feet (8.2 meters).

Huichica Formation

General Character. The Huichica Formation is of Pleistocene age and was named by Weaver (1949). The formation occurs only in a small area in the far southeastern portion of Sonoma County. The formation is of somewhat greater areal extent in adjacent areas of Napa County, and its type locality as described by Weaver (1949), is along Huichica Creek a short distance east of the Sonoma-Napa County line.

The Huichica Formation consists of deformed continental beds, with a maximum thickness estimated by Kunkel and Upson (1960) to be at least 900 feet (275 meters). The beds were deposited as alluvial fans that drained a highland to the north composed of Sonoma Volcanics. Hence, the formation consists of reworked tuff, weathered volcanic clay, silt, and similar materials; particles of pumice are common throughout the basal 200 feet (61 meters) of the formation. The beds are all poorly sorted and cross-bedding is locally abundant.

The Huichica Formation is of Pleistocene age and overlies the truncated beds of the Sonoma Volcanics. To the northwest it interfingers with the beds of the contemporaneous Glen Ellen Formation.

Water Quality. Only one analysis is available from a well tapping the Huichica Formation. This well produces a sodium bicarbonate ground water that contains 230 mg/l sodium ion. With an electrical conductivity of 1,100 micromhos, the water is classed as having a high salinity and high sodium hazard.

Well Yield. The Huichica Formation is considered to be a poor producer of ground water. According to Kunkel and Upson (1960), some wells tapping the Huichica Formation do not yield sufficient water even for domestic use. Well production data are available from five wells tapping this formation. Yields range from 10 to 100 gpm (38 to 378 l/m) with drawdowns ranging from 50 to 250 feet (15 to 76 meters). The specific capacities of these wells range from 0.04 to 1.1 gpm per foot (0.5 to 13.6 l/m per meter) of drawdown. One well, located near the intersection of Napa Road and State Sign Route 121, was drilled to a depth of 750 feet (229 meters). The log of the well indicates "blue sticky clay, yellow sticky clay, sand and gravel, gray clay, and tule mud" to a depth of 423 feet (129 meters). Below this are "blue shattered rock, red clay, and cemented sand and gravel" to a depth of 680 feet (207 meters), below which is basalt to the bottom of the well. A notation on the bottom of the well log indicates, "Flow began at 423 feet (129 meters), big flow is off the bottom".

Another well was drilled in the Huichica Formation along Ramal Road. This well went to a depth of 500 feet (152 meters) in a zone of brown clay, sand and gravel. Prior to testing, the well was reported to be flowing. Tested for 12 hours, the well produced 50 gpm (189 l/m), with a drawdown of 200 feet (61 meters). A notation on the well log indicates that the ground water in this well contained boron, and the well was capped.

Unconsolidated Materials

The unconsolidated materials are present in a great diversity of grain size, from coarse-grained stream channel deposits to the finest-grained materials occurring in basin areas. Included with these materials are such diverse deposits as alluvial fans, landslides, and both stream and marine terrace deposits. Each of the unconsolidated materials is briefly described below.

Older Alluvium. Older alluvium occurs in Sonoma Valley, Petaluma Valley, and in various parts of the Santa Rosa Plain. The older alluvium consists of lenticular beds of reddish brown, compacted silty clay, silt, sand, and gravel; hardpan and claypan frequently are present. The older alluvium is of Pleistocene to Holocene age and overlies the Glen Ellen and Huichica Formations. According to Cardwell (1958), the older alluvium may be correlative to a part of the Glen Ellen Formation. Cardwell (1958) reported the older alluvium as being up to 200 feet (61 meters) in thickness in the Santa Rosa-Petaluma area; Kunkel and Upson (1960) believed the older alluvium attained a maximum thickness of 500 feet (152 meters) in Sonoma Valley.

Ground water in the older alluvium is a moderately hard sodium-magnesium-bicarbonate water.

The older alluvium is not a prolific producer of ground water, and wells located on this unit usually produce from underlying materials. For example, a 50-foot (15-meter) well drilled near the intersection of Seventh Street East and East MacArthur

Street, southeast of Sonoma, went through a sequence of gray clay, yellow clay, and cemented gravel. Tested with a bailer, the well produced only 0.33 gpm (1.2 l/m). A nearby well, drilled near East Fifth Street and Denmark Street, went to a depth of 310 feet (94 meters). After passing through a sequence of brown, yellow, and blue clay from a depth of 58 to 300 feet (18 to 91 meters), the well entered a 10-foot (3-meter) zone of medium sand. On test, the well produced 30 gpm (113 l/m) with a drawdown of 100 feet (30 meters).

Marine Terraces. Deposits of poorly consolidated silt, sand, and gravel occur as discontinuous terraces along the Sonoma coast from Bodega Bay north to the Gualala River. The deposits are from 25 to 50 feet (7 to 14 meters) in thickness and are of Pleistocene to Holocene age. Marine terraces have been formed at a time that sea level stood higher than at present. In some places, notably in the vicinity of Salt Point and Ocean Cove, several distinct terrace levels may be seen. Median elevations for the various terraces in this area are 100, 300, 500, 700, and 900 feet (30, 91, 152, 213, and 274 meters). The presence of the uppermost terraces at elevations of 700 and 900 feet (213 and 274 meters) suggests vertical movement since deposition in connection with an emerging coastline.

Near Salt Point, a number of wells have been drilled in the area of the terraces. All of these pass through the terraces and bottom some distance into the underlying Tertiary marine sediments. Water levels in these wells usually are at or near the contact with the underlying rock, suggesting that the terraces are nearly all drained. Farther south, near Bodega Bay, shallow wells produce ground water from the marine terraces. Thronson (1963) estimated that the marine terraces contained only 2,700 acre-feet (3.3 hm^3) of ground water in storage. There are no data available concerning the quality of ground water contained in the marine terraces. Ground water contained therein should be potable unless affected by mineralized water derived from underlying sources.

Terrace Deposits. River terrace deposits of Pleistocene to Holocene age occur adjacent to the Russian River and Dry Creek. The deposits are discontinuous and consist of unconsolidated, cross-bedded deposits of sand and gravel that may be up to 200 feet (61 meters) thick. Some terraces overlie Franciscan rocks; others are underlain by Sonoma Volcanics and Glen Ellen sediments. The terrace deposits were formed when streams were at a higher grade level that at present. They were formed as alluvial fan or stream channel deposits and have been left isolated as the grade level in streams dropped.

Most terrace deposits may yield adequate quantities of ground water for domestic purposes, except where perched on top of knolls and thus drained. Along Dry Creek, several domestic wells have been completed in the terrace deposits. The wells range from 45 to 70 feet (14 to 21 meters) in depth. Yields range from 10 to 60 gpm (38 to 227 l/m), with reported drawdowns being from 0 to 10 feet (3 meters). The standing water level in these wells ranges from 10 to 20 feet (3 to 6 meters) below ground. In this same area, a well was drilled through the terrace deposits and completed in the underlying Glen Ellen Formation. This well yielded 175 gpm (663 l/m), with a drawdown of 40 feet (12 meters); the reported standing water level was 180 feet (54.8 meters).

The quality of ground water in the terrace deposits generally is excellent. The water is a sodium to magnesium-bicarbonate water.

Alluvial Fans. Alluvial fan deposits occur along the eastern side of the Santa Rosa Plain; minor fan areas also occur in Sonoma Valley and Alexander Valley. The alluvial fans are composed of a heterogeneous mixture of unconsolidated, poorly sorted gravel, sand, silt, and clay deposited by active streams draining the adjacent mountainous areas. The fan deposits are of Holocene age and range in thickness from 50 to over 200 feet (14 to over 60 meters).

Yields of wells drilled into the alluvial fan deposits are adequate for most domestic needs. One well drilled along Petaluma Hill Road went to a depth of 150 feet (46 meters) in yellow clay, boulders, and rocks. On test, the well produced 10 gpm (38 l/m), with a drawdown of 60 feet (18 meters). The standing water level was 50 feet (15 meters). Other wells in the vicinity produce somewhat less water due to intercepting less coarse material. At Sonoma State College, wells have been drilled to depths of 400 to 450 feet (122 to 137 meters) in the alluvial fan deposits and the underlying materials. These wells produce from 550 to 600 gpm (2,079 to 2,268 l/m), with drawdowns on the order of 85 feet (26 meters).

The water produced from the alluvial fans is hard and is of magnesium bicarbonate composition.

Younger Alluvium. Unconsolidated alluvium, consisting of beds and stringers of gravel, sand, silt, and clay, occurs in all valley areas of Sonoma County. The deposits are of Holocene age and were formed as floodplain deposits from such streams as Sonoma Creek, Santa Rosa Creek, and the Russian River. The alluvium usually ranges from 30 to 150 feet (9 to 45 meters) thick, and is highly variable in composition. According to Cardwell (1958), the alluvium may be up to 300 feet (91 meters) thick along Petaluma Creek.

Well yields are highly variable in the alluvium. In the Petaluma area, yields range from 10 to 40 gpm (38 to 151 l/m). A well drilled in the alluvium along Casa Grande Road went to 83 feet (25 meters) in mixed clay, gravel, and cemented gravel. The well produced 40 gpm (151 l/m), with a drawdown of 50 feet (15 meters). The standing water level was 27 feet (8.2 meters). In contrast, wells in the alluvium in areas along the Russian River, such as in Alexander and Cloverdale Valleys, produce large amounts of water. An example of this is a well drilled in cemented and loose gravels along River Road near Cloverdale. The well is 40 feet (12 meters) deep and produces 140 gpm (529 l/m), with no measurable drawdown. Standing water is at a depth of 14 feet (4.2 meters).

Ground water in the alluvium is generally of excellent quality. In the Petaluma area, Well No. 5N/7W-28A2 produces from the alluvium. The well is 99 feet (30 meters) deep and produces an excellent quality calcium-bicarbonate water. Near Cloverdale, Well No. 11N/10W-17C1, which is 15 feet (4.5 meters) deep, also produces an excellent quality calcium-bicarbonate water.

<u>Landslides</u>. Many landslides occur in the Franciscan terrain in the northwestern and northeastern part of Sonoma County. The deposits occur on steep slopes and are composed of a heterogeneous mixture of broken rock, clay, and some pebbles, cobbles, and boulders. Large blocks of Franciscan rock up to 30 feet (9 meters) across are not uncommon. Only the major landslides are shown on Plate 1; smaller slides are not shown. All slides are in some degree of failure, thus they are unstable and serve as poor foundations for roads and structures. Many slides have small ponds occupying the depressions at their heads; springs and seeps commonly occur along the toe areas.

A few wells have been drilled into the larger slide areas northeast of Cloverdale. These wells passed entirely through the slide area and presumably entered stable rock at depths of about 175 to 200 feet (53 to 61 meters). The intervening area was reported as a mixture of fractured rock, brown sandy clay, red clay, and "serpentine clay". One well has a yield of 40 gpm (151 l/m), with no drawdown; the standing water level was at 40 feet (12 meters). Another well yielded 50 gpm (189 l/m) and was reported to be flowing. Although no water quality data are available for wells in landslides, the ground water in the landslides is believed to be an excellent quality sodium- to magnesium-bicarbonate water.

<u>Stream Channel Deposits</u>. Deposits of coarse sand and gravel occur along the Russian River, Dry Creek, and other active streams in Sonoma County. The deposits are highly permeable and range in depth to 100 feet (30 meters). South of Healdsburg,

a well completed in the stream channel deposits produces 350 gpm (1,323 l/m) with a drawdown of 3 feet (1 meter); the specific capacity of this well is 117 gpm per foot (1,323 l/m per meter) of drawdown. According to Cardwell (1965), test wells drilled for the Sonoma County Water Agency near Wohler Bridge (8N/9W-29L) showed 53 to 85 feet (16 to 26 meters) of clean river sand and gravel. Tests at these wells indicated that the stream channel deposits had an average transmissivity of 850,000 gpd per foot (10,540 square meters).

Water quality data for ground water in the stream channel deposits are lacking. However, the water is presumed to be of the same quality as that in the adjacent stream.

Sand Dunes. Deposits of coastal dunes occur west of Bodega Harbor and at scattered localities along the coast north to the Gualala River. The dunes are composed of two basic types. Younger dunes are formed of loose, eolian sand that is deposited by the ocean and formed into dunes by the winds. Although highly permeable, the dunes contain little ground water. Some salt crystals may be present dispersed throughout the sand. Older dunes -- those with a cover of salt grass and other coastal plants -- occur some distance inland. The dunes have been arrested in their migration; they contain some lenses of silty clay. Ground water contained within these older dunes may be fresh and also may be perched over saline water.

No well yield data are available for wells drilled in the dune areas. Most dune areas apparently contain little usable ground water. Where ground water is present, wells probably produce adequate ground water for domestic use. Water levels in these wells may fluctuate markedly with the seasons, because long, dry periods will drastically lower the potentiometric surface of water in the dunes. The quality of ground water in the sand dune area is affected by adjacent bodies of salt water.

Bay Mud Deposits. Bay mud deposits occur in tidal areas of the lower Sonoma Valley and Petaluma Valley; a small area of bay mud also occurs on the west side of Bodega Bay. The bay mud deposits are composed of organic clay, silt, and fine sand; peat and decomposed tules may be present. The deposits have been formed from flocculation of turbid water flowing down the streams draining the adjacent highlands and also by natural deposition on the floor of San Pablo and Bodega Bay. The deposits are up to several hundred feet thick and are underlain by more consolidated deposits of older alluvium, Huichica Formation, Petaluma Formation, and Franciscan rocks. The deposits of bay mud, where exposed on land, range from fairly stiff to soft; after working, they are subject to heaving. On the floor of San Pablo Bay, the bay mud deposits range downward from ooze to soft fetid clay.

The bay mud is not considered a reliable source of potable ground water. Two wells were drilled in the bay mud deposits north of Midshipman Point on San Pablo Bay. One well went to a depth of 30 feet (9 meters) in gumbo and brown sandy gravel. It produced 1 gpm (3.8 l/m) with a drawdown of 19 feet (5.8 meters); the standing water level was 8 feet (2.4 meters). A nearby well was drilled to a depth of 239 feet (73 meters) and was completed in underlying materials. This well produced 40 gpm (151 l/m), with a drawdown of 25 feet (7.6 meters); the standing water was 30 feet (9 meters). The U. S. Navy Skaggs Island facility has several wells situated on bay mud deposits. All are completed in the underlying Huichica and related materials. These wells produce excellent quality sodium-bicarbonate water in contrast to shallow wells in the bay mud, which produce poor quality sodium chloride water.

Geologic Structure and its Effect on Ground Water

Structural features in the nonwater-bearing rocks of Sonoma County generally have little effect on movement or quality of ground water. Conversely, features in the water-bearing materials may act as barriers to ground water movement, as controlling features for the direction of ground water movement, and as source areas for certain mineral constituents found in ground water. Each of the two basic types of geologic structures, folds and faults, are briefly discussed below.

Folds

Several anticlines in the water-bearing materials are identified on Plate 1. The Washoe Anticline was named by Weaver (1949) for a structure in Merced sediments and Sonoma volcanics along Washoe Creek, west of Cotati. The anticline extends from the Denman Flat area northwesterly toward Gossage Creek, a distance of about 6 miles (10 kilometers). Meacham Hill lies parallel to and immediately west of the axis of the anticline. The limbs of the anticline are undulatory, and it branches into several parallel folds to the north. The anticline forms part of the southwestern boundary of the Santa Rosa ground water basin.

To the southeast is the Adobe Creek Anticline, also named by Weaver (1949). This feature is entirely within the Petaluma Formation and has a northwest-southeast strike parallel to the grain of the regional structure. The axis of this anticline presumably forms part of the northeastern boundary of the Petaluma ground water basin.

There are three synclines in Sonoma County which have some effect on the movement of ground water. The Windsor Syncline, named by Gealey (1950), is responsible for the formation of the topographic feature called the Santa Rosa Plain. The axis of this syncline runs from the vicinity of Rohnert Park northwesterly through Windsor toward Healdsburg. At the north end the syncline is an asymmetrical downwarp, with gentle dips on the west side and steeper dips coupled with some faulting on the east side. South of Mark West Creek the syncline becomes very complicated on the eastern side, as secondary folding and faulting has taken place. Another downfold in the water-bearing materials is the Kenwood Syncline. This structural feature runs from the vicinity of Glen Ellen northwesterly through Rincon Valley. Sediments of the Glen Ellen Formation are exposed on the flanks of the syncline, with the axial area being composed of Holocene alluvial materials.

In addition to the structural features in the Tertiary and Quaternary materials, there also is a syncline in the older Dry Creek conglomerate which affects ground water movement. This feature is the Geyserville Syncline, named by Gealey (1950). Folding has deformed the Cretaceous beds into a northwest-trending syncline which extends from near Geyserville northwesterly toward Dutcher Creek.

In all cases, anticlines and synclines affect the movement of ground water by inducing ground water movement downslope along the flanks of the features.

Faults

There are a great number of faults in Sonoma County, not all of which are shown on Plate 1. A great number of faults occur in the nonwater-bearing rock and because they have little effect on ground water, most are not shown on Plate 1. A few major faults are shown because they could be sources of ground water moving laterally along fracture zones. The faults of Sonoma County are of three basic types: lateral, vertical, and thrust. Lateral faults are those which displace beds in a horizontal direction with little or no vertical component of movement. The San Andreas Fault exhibits this type of movement. Vertical faults displace beds in a vertical direction, and thrust faults move older formations over younger ones.

Faults can form barriers to ground water movement if impermeable materials are brought into position opposite permeable, water-bearing rocks. Furthermore, in relatively nonwater-bearing rocks, faults can create shattered zones which could act as conduits for ground water movement. Ground water along some faults may contain slightly higher amounts of certain mineral constituents, such as fluoride and boron.

APPENDIX E

SOIL PERCOLATION TESTING CRITERIA

The following criteria for percolation test hole construction and testing have been adopted by the Sonoma County Public Health Service:

Number and Type of Test Holes

Private sewage disposal systems require one soil core hole and a minimum of three percolation test holes spaced uniformly through the area of the proposed leach field (including leach field expansion area). The percolation test holes shall be 6 to 8 inches (15 to 20 cm) in diameter and shall be of a depth as specified in Table 24, below. The proposed depth of percolation test holes must take into consideration whether subsequent grading and removal of soil would require deeper testing. The soil core hole shall be not less than 4 inches (10 cm) in diameter and shall be not less than 8 feet (2.4 m) in depth, if physically possible.

Table 24

MINIMUM DEPTHS OF PERCOLATION TEST HOLES

Average Ground Slope (percent)	Minimum Depth	
	(feet)	(meters)
10	3.0	1.0
11 - 15	3.6	1.1
16 - 20	4.4	1.3
21 - 25	5.1	1.6
26 - 30	5.9	1.8

Preparation of Percolation Test Holes

After all test holes have been dug, loose and slumped material shall be removed from each hole and the walls of the holes carefully cleaned to expose the native in-place materials. At the bottom of each test hole, a 2-inch (5-cm) layer of clean pea gravel shall be placed, upon which is rested the end of a 3-inch (7.5-cm) diameter section of perforated pipe. The annular space between the outside of the pipe and the wall of the hole shall then carefully be backfilled with clean pea gravel.

Presoaking of Percolation Test Holes

On the day prior to conducting the percolation tests, each test hole shall be filled with clear water and then refilled at least once and as many times as may be necessary to simulate actual operating conditions.

Percolation-Rate Measurements

Percolation-rate measurements shall be made on the day following the presoaking of the test holes, as follows:

1. When Water Remains from Presoaking: Record the inches of water reamining in the hole, and adjust the water level to 12 inches (30 cm) above the bottom end of the pipe. Water level measurements are then taken from the top of the pipe to the water level hourly for the next six hours.

2. When No Water Remains from Presoaking: Add clear water to a depth of 12 inches (30 cm) above the bottom end of the pipe. Measure the drop in water level hourly for the next six hours. When the water drains completely from the hole the first time, add water to a depth of 12 inches (30 cm); thereafter, add water to a depth of 12 inches (30 cm) whenever the depth of water in the pipe is less than 3 inches (7.5 cm).

3. When Hole is Dry After the First 30 Minutes: Add clear water to a depth of 12 inches (30 cm), and take water level measurements every 10 minutes for a period of two hours. Add water to a depth of 12 inches (30 cm) after hole is completely drained the first time; thereafter, add water to a depth of 12 inches (30 cm) whenever depth of water in the pipe is less than 3 inches (7.5 cm).

Percolation Rate

The drop in water level occurring between the fifth and sixth measurements on the 6-hour tests and between the eleventh and twelfth measurements on the two-hour tests is considered to be the stabilized percolation rate. The readings taken during the prior periods provide information for any modification of the stabilized percolation rate.

Soil Core Hole

A detailed description of the soil profile shall be prepared from the soil core hole. The description shall include information on depth of topsoil, depth to ground water, if encountered, and notations on any clayey material, hardpan, or rock strata.

Percolation Test Records

All percolation test data and information from the soil core hole shall be submitted to the Sonoma County Public Health Service on forms provided. Test records submitted for lot splits, proposed subdivisions, and engineered plans for sewage disposal shall include written evluation and certification by a registered civil engineer. Records submitted shall include a sketch or map showing the location of the percolation test holes and the soil core hole.

Wet Weather Percolation Tests

Land with a slope of 5 percent or less, and also that of greater than 5 percent if underlain by soils with a significant shrink-swell potential, require all percolation tests to be made: (1) during the period from November 1 to March 1, (2) after a total seasonal rainfall of 10 inches (25 cm) has occurred, and (3) immediately after 0.8 inch (2 cm) of rainfall has occurred during a 48-hour period. Rainfall figures shall be as reported by the Sonoma County Water Agency and based on readings taken at the Sonoma County Administration Center in Santa Rosa.

Leach Field Sites on Filled Land

Leach fields can be constructed on filled land provided the following requirements are met:

1. A log of the soil materials and ground water level in the area of the proposed filled land be prepared.

2. Soil percolation tests which fail to show a percolation rate faster than 60 mpi (25 m/cm) at hole depths of 3 feet (1 m) may be retested in new holes in native soils to a depth of 2 feet (0.65 m). Percolation rates in the new holes must be greater than 60 mpi (25 m/cm).

3. All leaching trenches require a minimum depth of 3 feet (1 m) of permeable native soil, or a combination of not less than 2 feet (0.65 m) of native soil and sufficient permeable fill material to achieve a total depth of 3 feet (1 m).

4. The absorptive quality of the fill material shall be equal to, or better, than that of the native soil materials. Sand, gravel, rock, or any mixtures thereof, do not constitute acceptable fill material.

5. Site specifications for the fill shall include that all vegetation is to be removed and the ground surface prepared to permit a good mixing of the native soil materials and the fill materials.

6. Filled land shall be constructed in layers not over 8 inches (20 cm) thick to the same compaction as the native soil. A soil compaction test shall be made, certified by a registered civil engineer, and submitted to the Public Health Office.

7. The filled area shall equal 150 percent of the maximum area required for the leach field. The fill shall be of uniform depth extending to a distance of 15 feet (5 m) in any direction from the center of any proposed leach trench. Where installed on sloping ground, the fill shall provide a minimum horizontal distance of 15 feet (5 m) between the nearest leaching pipe and daylight. An additional area equal to 150 percent of the leach field area shall be reserved for future expansion. The expansion area is required to be filled in the manner described above at the time of construction of the disposal system or, in the case of minor subdivision (lot splits), of lots sized one acre (0.4 ha) or less.

APPENDIX F

WATER QUALITY CRITERIA

Criteria presented in the following sections can be used to evaluate the quality of water relative to existing or anticipated beneficial uses. It should be noted that these criteria are merely guides to the appraisal of water quality. Except for those constituents considered toxic to human beings, these criteria should be considered as suggested limiting values. A water which exceeds one or more of these limiting values need not be eliminated from consideration as a source of supply, but other sources of better quality water should be investigated.

Domestic and Municipal Water Supply

The physical and chemical quality of drinking water is judged in relation to a set of criteria contained in Title 17, Part 1, Chapter 5, Subchapter 1, of the California Administrative Code and also set forth by the Environmental Protection Agency (1975).

The physical characteristics that are recommended for limiting in drinking water are: turbidity -- not to exceed 0.5 turbidity units for water exposed to significant sewage hazards; color -- not to exceed 15 units on the cobalt scale; and odor -- not to exceed 3 on the threshold odor number.

Limiting concentrations for most mineral constituents in drinking water are shown on Table 25. Upper limits for total solids, electrical conductivity, chloride, and sulfate are shown on Table 26. Limiting concentrations for fluoride are shown on Table 27.

Although hardness is not included in any of the above standards, it is important to domestic and industrial uses. Excessive hardness in domestic water supplies causes increased consumption of soap and formation of scales in pipes and fixtures. Table 28 shows the relative degrees of hardness in water.

Industrial Water Supply

The quality of water required by industry varies widely because of the many purposes to which water is put. These requirements are too variable to allow any broad generalization; however, for most processes, industry is generally willing to accept water that meets drinking water standards. One factor that is of

Table 25

LIMITING CONCENTRATIONS FOR
MINERAL CONSTITUENTS IN DRINKING WATER[1/]

(in milligrams per liter)

Mineral Constituent	Limiting Concentration
Arsenic	*0.10*[2/]
Barium	*1.0*
Cadmium	*0.01*
Chromium (Hexavalent)	*0.05*
Copper	*1.0*
Cyanide	*0.2*
Iron	*0.3*
Lead	*0.05*
Manganese	*0.05*
Mercury	*0.005*
Nitrate-N + Nitrite-N	*10.0*
Selenium	*0.01*
Silver	*0.05*
Zinc	*5.0*

1/ Title 17, California Administrative Code, Part 1, Chapter 5, Subchapter 1.

2/ *0.05 mg/l* proposed by Environmental Protection Agency (1975).

Table 26

UPPER LIMITS FOR TOTAL SOLIDS, ELECTRICAL CONDUCTIVITY, SULFATE, AND CHLORIDE IN DRINKING WATER 1/

	Recommended Limit	Upper Limit	Short-Term Upper Limit
Total solids, mg/l	500	1,000	1,500
Electrical conductivity, micromhos	800	1,600	2,400
Sulfate, mg/l	250	500	600
Chloride, mg/l	250	500	600

1/ Title 17, California Administrative Code, Part 1, Chapter 5, Subchapter 1.

Table 27

LIMITING CONCENTRATION FOR FLUORIDE IN DRINKING WATER 1/

Annual Average of Maximum Daily Air Temperature 2/		Fluoride Concentration 3/ (in mg/l)		
(°F)	(°C)	Lower	Optimum	Upper
50 - 54	10 - 12	0.9	1.2	1.7
55 - 58	13 - 14	0.8	1.1	1.5
59 - 64	15 - 18	0.8	1.0	1.3
65 - 71	19 - 21	0.7	0.9	1.2
72 - 79	22 - 26	0.7	0.8	1.0
80 - 81	27	0.6	0.7	0.8

1/ Title 17, California Administrative Code, Part 1, Chapter 5, Subchapter 1.
2/ Based on temperature data obtained for a minimum of five years.
3/ The average concentration of fluoride during any one month, if added, shall not exceed the upper limit, and if occurring naturally, shall not exceed twice the optimum.

Table 28

RELATIVE DEGREES OF HARDNESS
OF DRINKING WATER

Range of Hardness Expressed as $CaCO_3$ (in mg/l)	Relative Classification
0 - 100	Soft
101 - 200	Moderately hard
Greater than 200	Hard

primary importance to most industries is that the concentrations of the various mineral constitutents in water be relatively constant because variations in concentrations of constituents usually require continued attention and added expense.

Agricultural Water Supply

The concentration of salts in irrigation water is rarely high enough to cause immediate injury to crops. Good soil drainage is probably more important to crop growth because even when excellent-quality water is applied, poorly drained land could go out of production due to the salt build-up in water retained in the soil. The continual concentration of salts in the soil solution is the result of evapotranspiration by plants which use only the water fraction, leaving the salts behind. The soil solution can be rendered less saline only by downward leaching and by periodic application of less saline water.

A discussion of the quality of irrigation water must include the effects that the mineral constitutents contained in the water will have on both the plant and the soil. Potential detrimental effects on plant growth by salts occur in three areas: physical, chemical, and indirect. The physical effect that applied water has on plants is by the suppression of water uptake, i.e., the osmotic effect; the chemical effect is on the metabolic reactions of the plants to the mineral constituents in the water, i.e., the toxic effects; and the indirect effect occurs through changes in soil structure, permeability, and aeration.

Because of all of the variables involved, a classification of irrigation water cannot be rigidly set. A set of water quality guidelines has been proposed by Ayers and Branson (1974). These guidelines, which are shown on Table 29, show recommended limits for irrigation water as well as for water used for livestock and poultry.

Table 29

GUIDELINES FOR INTERPRETATION OF QUALITY OF WATER FOR AGRICULTURAL USES[1/]

Type of Water	Water Quality Guidelines: No Problem	Increasing Problems	Severe Problems
Irrigation Water			
Salinity			
Conductance in micromhos at 25°C	<750	750-3,000	>3,000
Permeability			
Conductance in micromhos at 25°C	>500	200-500	<200
Sodium adsorption ratio	<6	6-9	>9
Specific ion toxicity, root adsorption			
Sodium adsorption ratio	<3	3-9	>9
Chloride, mg/l	<142	142-355	>355
Boron, mg/l	<0.5	0.5-2.0	>2.0
Specific ion toxicity, foliar adsorption (sprinklers)			
Sodium, mg/l	<69	>69	--
Chloride, mg/l	<106	>106	--
Stock Water			
Livestock			
Total dissolved solids, mg/l	<3,000	3,000-7,000	>7,000
Poultry			
Total dissolved solids, mg/l	<3,000	3,000-5,000	>5,000

1 After Ayers and Branson (1974).

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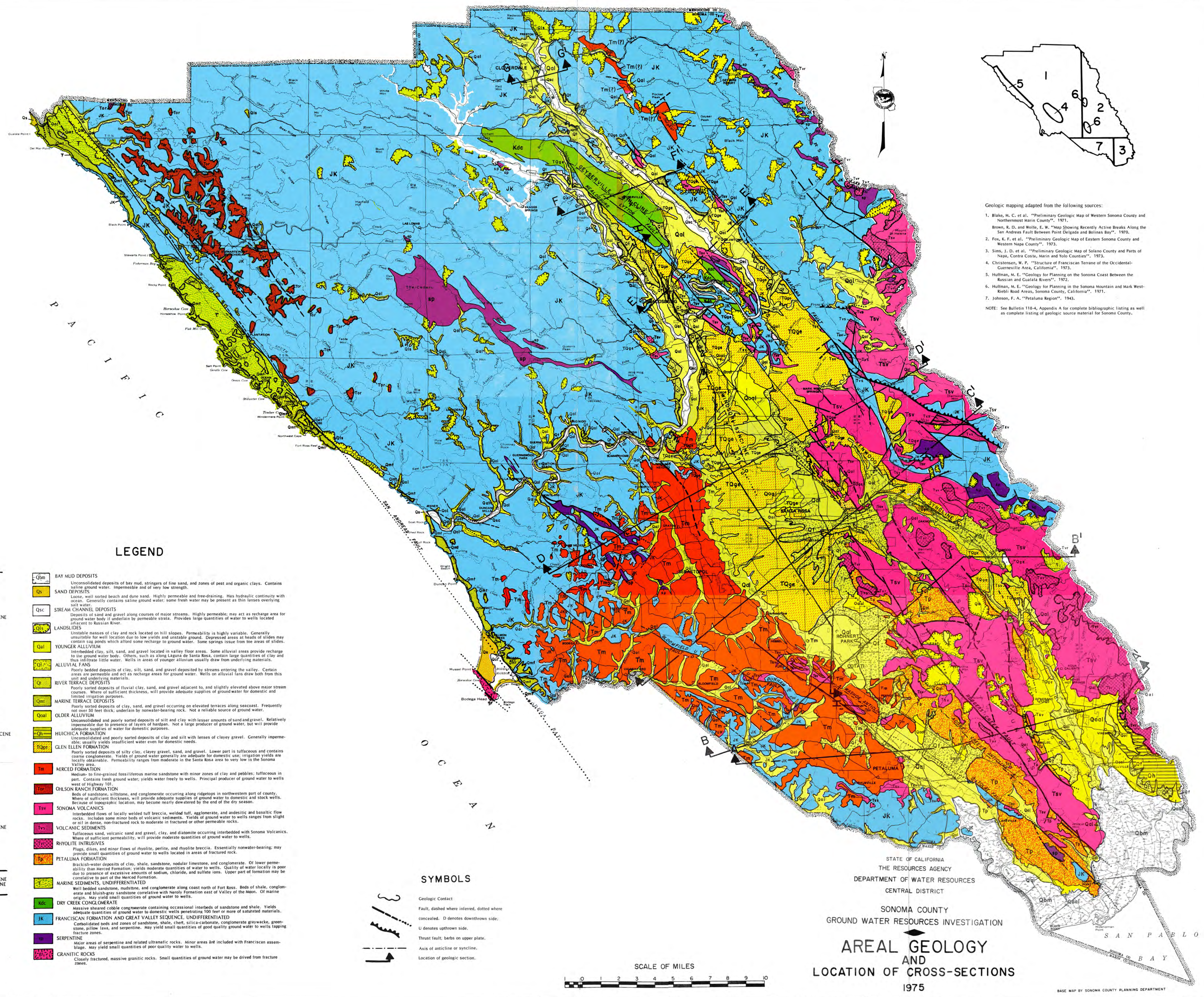

Geologic mapping adapted from the following sources:

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2. Fox, K. F. et al. "Preliminary Geologic Map of Eastern Sonoma County and Western Napa County". 1973.
3. Sims, J. D. et al. "Preliminary Geologic Map of Solano County and Parts of Napa, Contra Costa, Marin and Yolo Counties". 1973.
4. Christensen, W. P. "Structure of Franciscan Terrane of the Occidental-Guerneville Area, California". 1973.
5. Huffman, M. E. "Geology for Planning on the Sonoma Coast Between the Russian and Gualala Rivers". 1972.
6. Huffman, M. E. "Geology for Planning in the Sonoma Mountain and Mark West-Riebli Road Areas, Sonoma County, California". 1971.
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NOTE: See Bulletin 118-4, Appendix A for complete bibliographic listing as well as complete listing of geologic source material for Sonoma County.

LEGEND

QUATERNARY — HOLOCENE

Qbm — BAY MUD DEPOSITS
Unconsolidated deposits of bay mud, stringers of fine sand, and zones of peat and organic clays. Contains saline ground water. Impermeable and of very low strength.

Qs — SAND DEPOSITS
Loose, well sorted beach and dune sand. Highly permeable and free-draining. Has hydraulic continuity with ocean. Generally contains saline ground water; some fresh water may be present as thin lenses overlying salt water.

Qsc — STREAM CHANNEL DEPOSITS
Deposits of sand and gravel along courses of major streams. Highly permeable; may act as recharge area for ground water body if underlain by permeable strata. Provides large quantities of water to wells located adjacent to Russian River.

Qls — LANDSLIDES
Unstable masses of clay and rock located on hill slopes. Permeability is highly variable. Generally unsuitable for well location due to low yields and unstable ground. Depressed areas at heads of slides may contain sag ponds which afford some recharge to ground water. Some springs issue from toe areas of slides.

Qal — YOUNGER ALLUVIUM
Interbedded clay, silt, sand, and gravel located in valley floor areas. Some alluvial areas provide recharge to the ground water body. Others, such as along Laguna de Santa Rosa, contain large quantities of clay and thus infiltrate little water. Wells in areas of younger alluvium usually draw from underlying materials.

Qf — ALLUVIAL FANS
Poorly bedded deposits of clay, silt, sand, and gravel deposited by streams entering the valley. Certain areas are permeable and act as recharge areas for ground water. Wells on alluvial fans draw both from this unit and underlying materials.

Qt — RIVER TERRACE DEPOSITS
Poorly sorted deposits of fluvial clay, sand, and gravel adjacent to, and slightly elevated above major stream courses. Where of sufficient thickness, will provide adequate supplies of ground water for domestic and limited irrigation purposes.

QUATERNARY — PLEISTOCENE

Qmt — MARINE TERRACE DEPOSITS
Poorly sorted deposits of clay, sand, and gravel occurring on elevated terraces along seacoast. Frequently not over 50 feet thick; underlain by nonwater-bearing rock. Not a reliable source of ground water.

Qoal — OLDER ALLUVIUM
Unconsolidated and poorly sorted deposits of silt and clay with lesser amounts of sand and gravel. Relatively impermeable due to presence of layers of hardpan. Not a large producer of ground water, but will provide adequate supplies of water for domestic purposes.

Qh — HUICHICA FORMATION
Unconsolidated and poorly sorted deposits of clay and silt with lenses of clayey gravel. Generally impermeable; usually yields insufficient water even for domestic needs.

TQge — GLEN ELLEN FORMATION
Poorly sorted deposits of silty clay, clayey gravel, sand, and gravel. Lower part is tuffaceous and contains coarse conglomerate. Yields of ground water generally are adequate for domestic use; irrigation yields are locally obtainable. Permeability ranges from moderate in the Santa Rosa area to very low in the Sonoma Valley area.

TERTIARY — PLIOCENE

Tm — MERCED FORMATION
Medium- to fine-grained fossiliferous marine sandstone with minor zones of clay and pebbles; tuffaceous in part. Contains fresh ground water; yields water freely to wells. Principal producer of ground water to wells west of Highway 101.

Tor — OHLSON RANCH FORMATION
Beds of sandstone, siltstone, and conglomerate occurring along ridgetops in northwestern part of county. Where of sufficient thickness, will provide adequate supplies of ground water to domestic and stock wells. Because of topographic location, may become nearly dewatered by the end of the dry season.

Tsv — SONOMA VOLCANICS
Interbedded flows of locally welded tuff breccia, welded tuff, agglomerate, and andesitic and basaltic flow rocks. Includes some minor beds of volcanic sediments. Yields of ground water to wells ranges from slight or nil in dense, non-fractured rock to moderate in fractured or other permeable rocks.

Tvs — VOLCANIC SEDIMENTS
Tuffaceous sand, volcanic sand and gravel, clay, and diatomite occurring interbedded with Sonoma Volcanics. Where of sufficient permeability, will provide moderate quantities of ground water to wells.

Tvr — RHYOLITE INTRUSIVES
Plugs, dikes, and minor flows of rhyolite, perlite, and rhyolite breccia. Essentially nonwater-bearing; may provide small quantities of ground water to wells located in areas of fractured rock.

Tp — PETALUMA FORMATION
Brackish-water deposits of clay, shale, sandstone, nodular limestone, and conglomerate. Of lower permeability than Merced Formation; yields moderate quantities of water to wells. Quality of water locally is poor due to presence of excessive amounts of sodium, chloride, and sulfate ions. Upper part of formation may be correlative to part of the Merced Formation.

TERTIARY — PALEOCENE TO MIOCENE

T — MARINE SEDIMENTS, UNDIFFERENTIATED
Well bedded sandstone, mudstone, and conglomerate along coast north of Fort Ross. Beds of shale, conglomerate and bluish-gray sandstone correlative with Neroly Formation east of Valley of the Moon. Of marine origin. May yield small quantities of ground water to wells.

CRETACEOUS

Kdc — DRY CREEK CONGLOMERATE
Massive sheared cobble conglomerate containing occassional interbeds of sandstone and shale. Yields adequate quantities of ground water to domestic wells penetrating 100 feet or more of saturated materials.

JURA-CRETACEOUS

JK — FRANCISCAN FORMATION AND GREAT VALLEY SEQUENCE, UNDIFFERENTIATED
Consolidated beds and zones of sandstone, shale, chert, silica-carbonate, conglomerate graywacke, greenstone, pillow lava, and serpentine. May yield small quantities of good quality ground water to wells tapping fracture zones.

sp — SERPENTINE
Major areas of serpentine and related ultramafic rocks. Minor areas are included with Franciscan assemblage. May yield small quantities of poor quality water to wells.

gr — GRANITIC ROCKS
Closely fractured, massive granitic rocks. Small quantities of ground water may be drived from fracture zones.

SYMBOLS

Geologic Contact

Fault, dashed where inferred, dotted where concealed. D denotes downthrown side; U denotes upthrown side.

Thrust fault; barbs on upper plate.

Axis of anticline or syncline.

Location of geologic section.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY
GROUND WATER RESOURCES INVESTIGATION

AREAL GEOLOGY AND LOCATION OF CROSS-SECTIONS

1975

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